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ICEDIG.EU *Innovation and consolidation for large scale digitisation of natural heritage*

Natural history collections and digital skills of citizens

Deliverable 5.3

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1- University of Tartu Natural History Museum
2- Natural History Museum, London
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1. Introduction

In the history of science, natural history collections have played a major role. Darwin's famous Galapagos finches, for example, contributed to his theory of evolution, and remain preserved at the Natural History Museum, London, witnessing this development in how we understand the World. Today, museums hold not just preserved materials and paper records, but also vast amounts of information about specimens, their collection localities, collectors and methods of collection, as well as the analyses performed on them. Sophisticated databases and data management tools will drive research, education and policy making to the frontlines of development and growth in society.

Natural history museums carry some important functions for society: assembly, care and classification of collections; education; and research (Evans, 2014). With the support of modern technology, many of these functions are becoming increasingly interactive, with the potential to engage wider audiences in an information-hungry world. Digital solutions allow information to move quickly between collected specimens, researchers, policy makers, citizen scientists and learners. Data from over 190 million specimens and samples are already available through the Global Biodiversity Information Facility portal ("GBIF," n.d.). Similarly, with the OpenUp initiative, multimedia content from 12 European countries (some 8.7 million records) was submitted to the Europeana portal("Opening up the Natural History Heritage for Europeana," n.d.). With this proliferation of data and tools, it is increasingly easy for citizens to actively contribute to the creation and extraction of collection and observation data, and for such data to be used in learning

The very first contacts with natural history museums are often at a young age, while visiting museums with parents or during formal or informal education programs. For a future citizen scientist, these first experiences often lay the foundations of understanding what a museum is and how its collections contribute to knowledge and science. They can also determine the likelihood of returning in future as a volunteer.

In ICEDIG task 5.1 we reviewed the relationships between collections, particularly digital collections; formal and informal education; museum-related citizen science; and the skills and knowledge that these can advance. This is a complex area – defining types of education alone is a subject for wide-ranging research – and we have not attempted to reproduce all of that research in this report. Other ICEDIG tasks are also covering crowdsourcing (e.g. costs and platforms for transcription) in greater detail. We have therefore focused primarily on case studies and reviews of practice that we hope will be of practical help to collections-holding institutions, with a particular focus on digital collections, culminating in an outline business model for future projects. While regional and cultural differences can have an impact on citizen science and education, we would suggest that generally the similarities – for example in what approaches are likely to engage people – are more important than the differences.

2. Collections – interactions with citizen science, informal education and public participation

2.1. Best practice and case studies in citizen science and audience selection – an introduction

While the number of citizen science, informal education and participation projects solely focused on digital collections and transcription is relatively few, digital collections data is relevant to many such projects, for example to provide identification material or promotional content. As part of reviewing the current state of such projects in relation to digitisation, this section briefly reviews wider best practice and how it may apply in the context of digital collections.

The European Citizen Science Association has published 10 Principles of Citizen Science (ECSA, n.d.) (available in multiple languages), which underlie best practice in this area. Key to these principles are the involvement of participants in real scientific endeavour, with genuine benefit and regular feedback. This is certainly applicable to projects that focus primarily on digital collections and transcription - regular engagement with users, including a clear explanation of how they are contributing and how their work is being used, is fundamental to attracting and retaining participants. Similarly, even in more short-lived informal education or participation such as a short stop at a stand to handle objects, a sense of why these are important is key.

A “Guide to Citizen Science”(Tweddle et al., 2012) has also been produced by the UK Environmental Observation Framework, the NHM London, and the Biological Records Centre. This notes that:

“Over the past decade, there has been a rapid increase in the diversity and scale of citizen science. Initiatives range from crowd sourcing activities, in which the time and effort of large numbers of people are used to solve a problem or analyse a large dataset, to small groups of volunteers, who are experts in their own right, collecting and analysing environmental data and sharing their findings.”

The Guide again explores best practice in citizen science, and the varieties of projects and approaches. Relevant to digital collections, it notes that citizen scientists have most commonly been used as “data collectors” (e.g. taking observations of various kinds - often “born digital” information which could be construed as part of a digital collection in some circumstances), but that they can also be “data interpreters”, using human pattern recognition and analysis skills for activities such as transcription or image analysis of various kinds.

The Guide also looks at the stages of a project, from designing and testing something engaging, to live implementation and support, and ultimately analysis. As this points out, early attention to the data requirements of the project is critical, and indeed to the aims of the project as a whole. When, for example, the NHM London carried out crowdsourcing projects for transcription of microscope slide labels in 2017-18, they found that although projects could work to engage an audience of enthusiasts, the quality of data collected made it too expensive to ingest into their Collections Management System - overall, because the key aim of these pilots had been to test crowdsourcing as a mass transcription solution rather than for engagement or other purposes, they were stopped because transcription by trained digitisers or automated data capture (e.g. through barcodes) was more cost-effective. ICEDIG Work package 4 will produce a cost analysis of transcription methods (deliverable 4.5).

2.1.1. Defining target groups - audience segmentation

A key element of running successful projects is understanding who might participate in them. Segmentation of a market or audience is a concept that began in marketing and is now widespread as an approach to target and position products and services. Segmenting a Museum's actual and/or potential audience can help to: understand gaps or opportunities; provide services or experiences that respond better to audience wants and needs; and target particular offers to particular segments to secure better outcomes. This is likely to be particularly important for the projects discussed in this chapter to achieve the desired outcomes, although is relatively limited at present. This section therefore provides a short overview of audience segmentation, with examples of its application to Museums and to citizen science. Natural history museums here represent an example of collection holding institution with strong links to general public and citizen scientists. We suggest that our analysis can be used as a model for other similar institutions.

Segments can be devised based on need/intended outcomes, and on the level of data available. Broad types – which can also represent levels of maturity – are below.

1. Segmentation based on **socio-demographic attributes** which are observable and/or readily quantifiable, whether captured by yourselves or available from external sources. These are typically geographic and demographic (e.g. gender, age group, ethnicity, social 'grade', size of family or visit group; or for an organisation number of employees/clients/visitors and similar). These can reveal gaps in audiences; and allow for basic targeting. Segmentation based on such attributes is also helpful in identifying questions or subjects for the next stages.

2. Segmentation based on observable **behaviours,** whether online or in person (such as timing of visits, repeat visits, donation behaviour, physical or digital navigation/journeys and dwell times etc). By putting (1) and (2) together you can start to reach insights such as 'Women over the age of 30 are most likely to visit us on weekdays in the school holidays' (an invented example), and tailor your offer accordingly, either to suit your existing audience or to test ways to broaden it. But behaviours may change in unpredictable ways and insights require regular checking based on consistent data. Unexplained changes may indicate a need for further qualitative research.

3. Segmentation based on **attitudes and lifestyle** ('psychographic' segmentation) – usually based on custom-designed qualitative research (surveys, structured interviews and/or focus groups) rather than external sources, which may be targeted to answer a particular question, or to turn segments into 'personas' or profiles - detailed, lifelike characters to represent segments. This gets closer to <u>why</u> particular things are happening – e.g. it takes into account expressed wishes, intentions or reactions; and/or wider factors such as interests, attitudes to technology and similar. Attitudinal segmentation can provide more lasting insights.

Cutting across all these are **contextual or situational** factors such as life events – e.g. is a visit or purchase driven by a celebration; has someone moved into your area etc. The importance of inclusive and contextual approaches is discussed in E. Dawson & E. Jensen 2011 (Dawson and Jensen, 2011).

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It’s often possible to segment audiences based on in-house or freely available data, at least in the first instance, but outsourcing can be helpful e.g. to supplement skills (such as questionnaire design or data analysis); if your audience may respond better/more honestly to a ‘neutral’ third party asking a question; or to help reach a particular group e.g. to recruit a focus group of people with a particular socio-demographic profile. Further details including examples are included in this chapter from Americans for the Arts
https://namp.americansforthearts.org/sites/default/files/documents/practical-lessons/lesson_3.pdf

2.1.2 Defining audiences and target groups for Museums: Case study - the Natural History Museum, London (NHM)

The NHM has been segmenting its audience since 2005, using a variety of methods including geo-demographic; behavioural and attitudinal models. Segments look both at areas for growth, and areas for deepening engagement.

Sources for segmentation of physical visitors include:

- Sampled, i-Pad based exit surveys with visitors (as part of a consortium of free museums and galleries in London, giving a higher level of overall insight/responses) - these capture both geo-demographic and attitudinal information such as visitor satisfaction and reasons for visits
- Self-selecting exhibition exit surveys
- Visitor numbers (collected by a commercial system using cameras)
- Ticket sales data
- TGI (Target Group Index) data - TGI is the longest established single source marketing and media survey in Britain (now available in many other countries).

One insight from these surveys is that (at least up to 2017) less than ⅓ of general visitors know anything about the scientific work of the NHM - showing a clear gap and opportunity to improve this through informal education.

Occasional research has also been conducted with non-visitors, for instance to investigate reasons when visitor numbers showed a decline.

Specific focus groups have been used to explore particular segments, e.g. to improve understanding of NHM’s family audience - showing that a high percentage of families say that part of their motivation for visiting is to encourage children’s interest in art / history / the natural world and/or the world around them, but that many don’t perceive the Museum as a science destination or as sufficiently interactive.

Increasingly, digital data is used to inform segmentation and targeting. This includes both physical audiences - e.g. data about movement through the Museum based on connections to free Museum Wi-Fi - and online audiences, both on- and off-platform (i.e. Museum website / apps, or social media). As with previous segmentation, this captures geo-demographic information such as location of users as a base; as well as behavioural information such as times of day, dwell times and preferred devices. Insights generated include e.g. seasonality of interest in particular topics; or search terms used to find content. Digital analytics make it easier to see the impact of changes rapidly, for example using A/B testing where different options for layout or wording are tested to measure impact.

The NHM's Angela Marmont Centre for UK Biodiversity (AMC) use self-selecting surveys in Citizen Science projects to collect some demographic data and establish how people have decided to be involved (e.g. whether independently; through a group; or through education). Participants are grouped as follows:

- Family/friends (adults only)
- Family/friends (adults and children)
- Primary school
- Secondary school
- College/university
- Other youth group
- Adult volunteer group
- Other (please describe)

At present, while the Museum has started to track some conversions e.g. from online visitors to ticket purchase, it is not yet able to track conversion to deeper engagement with learning e.g. through participation in Citizen Science projects, but this would be the ideal.

NHM are currently partners in LEARNCitSci - a four-year international collaborative research project that aims to understand how young people develop environmental science agency through their participation in Citizen Science programs at Natural History Museums. Results of this research will be published in due course.

2.2. Informal learning and natural history collections

Natural history museums present a remarkable opportunity to link collections, the research and discoveries based on them, and the experiences they offer to the millions of people they are serving each year (Watson and Werb, 2013). Museums are traditionally seen as repositories of the past, places to see and marvel at things that once were. But the collections held within natural history museums in particular have the opportunity to engage visitors and to prepare them for the global problems we are facing such as climate change, biodiversity decline and food instability. Education is the key element in this process and one of the three functions of natural history museums, others being assembling / developing collections; collections care; and research (Evans, 2014).

Education can be categorised as formal and informal, often also a third category - non-formal - is used. Definitions for these categories vary, especially for informal education. Formal education is usually linked with training institutions - schools and universities - and prescribed curricula (often set or defined by government or central institutions).

For our purposes, we understand informal education as any education outside formal school settings or university qualifications. We are not strictly observing the linkage with school curricula, as in many cases it is difficult to distinguish if the educational activity is attended for the sake of school curricula or as extracurricular activity. This kind of analysis is also out of scope of our study.

Natural history collection holders, especially museums, have established themselves as important actors in informal education, providing rich content for out-of-classroom studies and activities.

Braund and Reiss (Braund and Reiss, 2006) describe five ways in which out-of-classroom contexts can add to and improve the learning of science:

1. Improved development and integration of concepts.

2. Extended and authentic practical work.

3. Access to rare material and to “big” science.

4. Attitudes to school science: stimulating further learning.

5. Social outcomes: collaborative work and responsibility for learning.

Natural history collection holders can at least to some degree be involved in every of these five aspects, but strikingly so in giving access to rare material and “big” science.

2.2.1. Methods

To assess natural history collection holders as educational actors and also estimate the use of collections and digitised content in educational activities, we conducted a qualitative survey of three contrasting natural history collection holders.

Questionnaire

We evaluated informal educational programs in respect of the use of natural history collections in their teaching and communication methods. Three institutions carried out the survey: The Natural History Museum, London (NHM), University of Tartu Natural History Museum (UTARTU), and Meise Botanic Garden (MEISE). All of them are involved in ICEDIG task 5.1.

Every institution listed their programs or educational activities and evaluated them in three aspects - use of scientific collections, use of exhibitions, and use of digital collections information. To create common understanding of these aspects we presented definitions as follows:

> ***Scientific collections*** *are kept in storage rooms and curated by specialists. They could be used for education programs while visiting storage rooms or arranged for use in program outside storage facilities.*
>
> *In* ***exhibitions*** *specimens are publicly exposed and usually provided with additional information and arranged for optimum display.*
>
> ***Digital collections information*** *can be photos of specimens or occurrence data (also in form of maps or graphs) or other data linked to specimens. This information can be available*

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publicly online or in institutional information systems.

In addition to actual use of collections, institutions evaluated the potential for further use. For evaluation, we used four-point scale for both actual and potential use:

0 - no use

1 - low (used in less than 25% of activities of particular program)

2 - moderate (used in 25-75% of activities of particular program)

3 - high (used in 75-100% of activities of particular program)

Interviews

In addition to the questionnaire, every partner interviewed education specialists or managers to reveal details of how collections - particularly digital collections - are used and the potential for additional use in the context of informal education programs. We used semi-structured interviews, where the main survey questions were presented by interviewers in the form of free conversation. Interviews could also conducted as group interviews where several interviewees are discussing the subject at the same time.

Main questions in interviews:

- How are you using collection materials - physical or digital - in educational programs or informal learning?
- What do you see as opportunities for and barriers to further use of physical and digital collections?
- If you are not using collections - physical or digital - in education, what are the reasons?
- What potential do you see for additional use of physical or digital collections in your work (give examples)?

Institution profiling

To describe the educational capabilities of each institution, we profiled them, using following characteristics:

- Publicly accessible exhibitions
- Designated rooms for educational activities
- Specialised/trained staff for educational activities
- Designed educational programs for schools / groups
- Online content (virtual exhibitions, informational web-pages) for education
- Whether curators are participating (in any way) in educational activities

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All of the characteristics can be further detailed.

2.2.2. Results

Institution profiles

Botanic Garden Meise	
Public exhibition	exhibition rooms are sometimes temporarily used for NH objects. Examples: seed exhibition, Dodoens exhibition. In the near future (spring 2019), wood collections will be permanently shown in the Woodlab.
Designated rooms for educational activities	classrooms and customised exhibitions
Educational staff	3 education officers, head of Public Services, approx. 20 freelance animators for school programs
Curators participation	for bachelor students program
Designed educational programs for schools / groups	yes, https://www.plantentuinmeise.be/nl/bezoek/Onderwijs
Online educational content	no

University of Tartu Natural History Museum	
Public exhibition	zoological , botanical, mycological and geological.
Designated rooms for educational activities	2 classrooms, education and lecture area in exhibition hall, room for temporary exhibition which can be customised for educational programs
Educational staff	educational specialist/program managers, 2 communication experts, designer, head of department
Curators participation	no
Designed educational programs for schools / groups	yes
Designed online educational programs	online collections, educational applications

Natural History Museum, London	
Public exhibition	majority of permanent and temporary exhibition space uses NH collection items, including fossils, minerals, mammals, botany, insects etc (majority larger specimens)
Designated rooms for educational activities	- 'Investigate Centre' for schools and families http://www.nhm.ac.uk/visit/galleries-and-museum-map/investigate.html

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	- Learning rooms (classrooms/training rooms) - Use of other spaces for planned and drop-in activities e.g. Wildlife Garden (activities such as pond dipping). - Angela Marmont Centre (AMC) for UK biodiversity offers identification facilities/service and space for classes (used for volunteers, adult education etc, but not for schools) http://www.nhm.ac.uk/take-part/centre-for-uk-biodiversity.html Also see http://www.nhm.ac.uk/take-part/identify-nature.html - 'Specimen Preparation Area' used for some volunteering activities with collections (includes window for public view)
Educational staff	Exhibitions, Learning and Outreach central team including research into audiences and learning; Learning programme developers; direct, trained Science Educators 14.5 FTE; and trained learning volunteers. These teams are involved in both formal and informal learning.
Curators participation	providing talks at events such as Nature Lives (and online equivalents) (free - http://www.nhm.ac.uk/visit/exhibitions/nature-live.html) and Dinosnores (paid events – childrens' and grown ups' versions); supporting special events / demonstrations; carrying out identification for AMC; However curators are not usually involved in day to day schools visits/educational offer.
Online educational content	- Schools offer (digital and physical e.g. see activities by key stage): http://www.nhm.ac.uk/schools.html - Naturenauts games and other Dippy on Tour resources (accompanies 'Dippy on Tour' national tour/exhibition of diplodocus cast): http://www.nhm.ac.uk/take-part/naturenauts.html - 'Discover' area of website for visitors and online audience to engage more deeply with collections http://www.nhm.ac.uk/discover.html - #NHM_Live online material to extend nature lives audience http://www.nhm.ac.uk/visit/exhibitions/nature-live.html
Designed educational programs for schools / groups	Yes - physical and online schools offer summarised here: http://www.nhm.ac.uk/schools.html Also wider education and training including volunteering, citizen science projects and training: http://www.nhm.ac.uk/take-part.html

Profile comparison table

	NHM London	MEISE	UTARTU
Public exhibition	Yes - most collection types used in both permanent and	Mostly botany-related exhibits	Zoological, botanical and geological permanent exhibition

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	temporary exhibits		halls
Rooms for educational activities	Several, including traditional classrooms, hands-on centre and outdoor space	Several, including traditional classrooms	Two classrooms, educational area in permanent exhibition hall
Staff for educational activities	Exhibitions, Learning and Outreach central team including research into audiences and learning; Learning programme developers; direct, trained Science Educators 14.5 FTE; and trained learning volunteers	3 education officers, head of Public Services, approx. 20 freelance animators for school programs	6 educational specialists/program managers, 2 communication experts, designer, head of department
Programs for schools / groups	Yes	Yes	Yes
Online content	Schools offer (digital and physical e.g. see activities by key stage): http://www.nhm.ac.uk/schools.html Naturenauts games and other Dippy on Tour resources (accompanies ‘Dippy on Tour’ national tour/exhibition of diplodocus cast): http://www.nhm.ac.uk/take-part/naturenauts.html ‘Discover’ area of website for visitors and online audience to engage more deeply with collections http://www.nhm.ac.uk/discover.html #NHM_Live online material to extend nature lives audience http://www.nhm.ac.uk/visit/exhibitions/nature-	Not specifically for education	Online collections, educational applications

	live.html		
Curators participation	Yes, providing talks and demonstrations	For bachelor student programs	No

2.2.3. Main uses of collections in education: conclusions from interviews

Information from interviews was used to identify the main categories of uses of collections in formal and informal education by the institutions involved in the task.

SPECIMENS

Collection visits

Giving access to collections for the general public or school groups (usually with guidance of a curator) helps to develop understanding of the essence and importance of natural history collections and create a more specific understanding how collections are managed and compiled. There are popular events (such as European Researchers Night or Long night of museums) which are perfect opportunities to raise awareness and show collections to the general public.

Reference for identification

Collection specimens can be used for learning principles of identification in general or for identifying specific species groups. This activity can be fulfilled with individual visits in collection facilities or with organized group workshop in various settings. During Bioblitzes for example the specimens are identified in field, and for that purpose specific reference collections can be used. Reference collections are usually kept separately from main collections. Occurrence data of reference collections may or may not be stored in collection management systems. Reference collections can be called also "learning collections" or "handling collections" and curated by educational department.

If the institution is working with citizen scientists e.g. on monitoring projects, collections can be used to raise the identification skills of participants for specific project and species group. Collection specimens can also be used to assess the skill level of participant.

Learning taxonomy and morphology

When studying specimens, realistic ideas about characteristics of the species or taxon groups, e.g. the weight, smell, and texture can be experienced only with actual objects, not with photos or 3D images.

IMAGES

Crowdsourcing

Images can be used for crowdsourcing projects. In such a case an image of specimen or label will be displayed in a specific portal for general public (for citizen scientists). Citizen scientists will use their skills to categorise images, transcribe labels etc. Often the participation involves a learning process to raise the skills which are needed for the task.

Learning taxonomy and morphology

Images of specimens as illustrations can help with identification and learning for certain features of natural objects, e.g. to learn similarities or differences of systematic groups etc. Images of botanical specimens, for example, can be used in this way. This can be done in classroom or at home.

OCCURRENCE DATA

School study projects

Based on specimen occurrence data (and related metadata), various educational study projects can be carried out.

CHALLENGES IN USING COLLECTIONS FOR EDUCATION

Research vs education

The main objective of creating and managing scientific natural history collections is to support research. This will often limit the opportunities for education or in some cases the collection items cannot be used for educational purposes. Working on the compromises will need active involvement of both educational and collection management staff. Not all types of collections are suitable for educational goals – some objects are extremely fragile and handling would risk destroying them.

There are also differences in age groups – which objects are suitable for hands-on education and which not.

Institutions have different practices in using collections for education. Decision of the curator can affect the availability of items or access to collection. General logistics for accessing collections may not be suitable for educational programs to take place there.

Availability of digital materials

There are gaps in digitized content of collections, some taxonomic groups are less covered than others.

Technological bottlenecks

Although images and occurrence data can be available for educational purposes, using them in practice can be difficult or not effective – either because it is not attractive for students or the educator might lack the skills or experience in using the relevant applications and digital solutions.

Suitability of specimens and/or images for educational purposes

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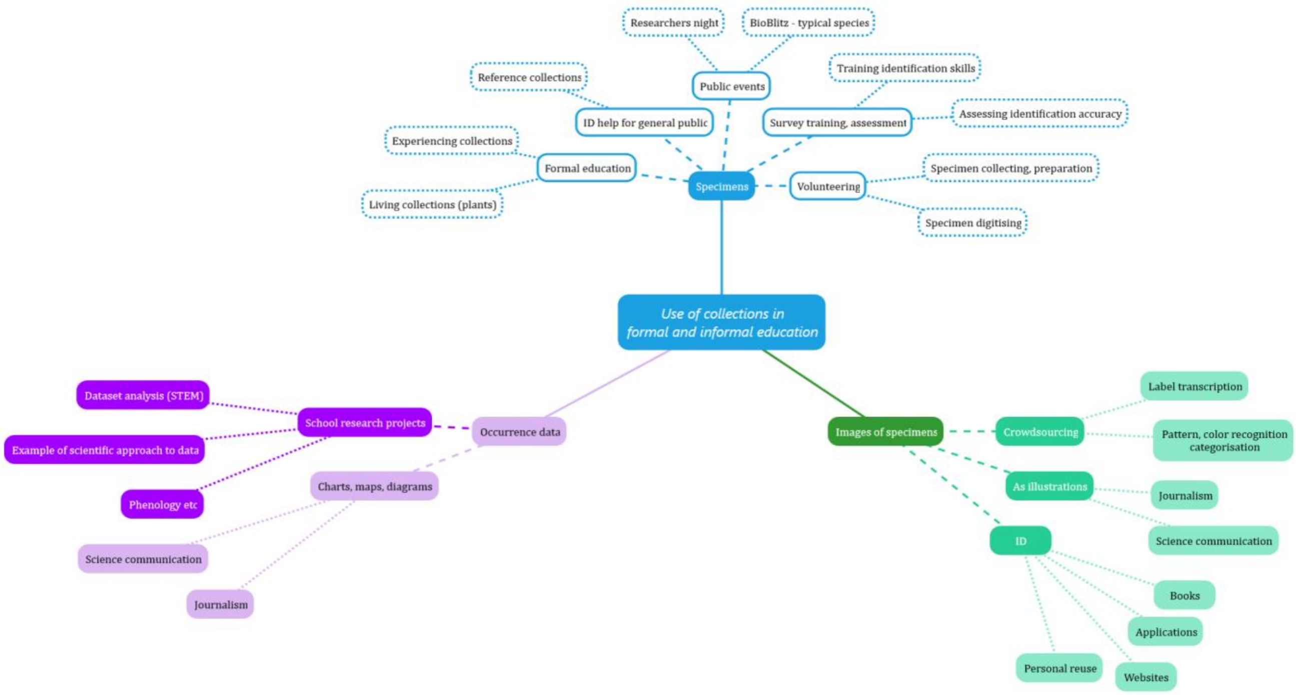
Images may not present important features of the object so it could be used in educational process effectively. Specimens can lose original color and shape during preparation and/or after certain time.

Cost effectiveness

With crowdsourcing projects the actual value of involving volunteers can be debatable. If crowdsourcing includes educational component, this increases cost but also benefits. Working with volunteers and citizen scientists needs extra time for staff.

Based on the interview results we can draw a concept map describing some uses of natural history collections in formal and informal education:



2.2.4. Evaluation of educational programs

Overall, 76 programs were evaluated by three organisations, some of them were aggregated for the analysis later.

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List of programs after aggregation

University of Tartu Natural History Museum and Botanical Garden	Educational programs for schools
	Hobby class of zoology
	Weekend family events
	School-break nature workshops
	Nature evening lectures
Botanical Garden Meise	Bachelor students visits
	Primary school visits
	Secondary school visits
	Guided visits for adults
	Crowdscourcing platform
Natural History Museum, London	Dippy on Tour - physical and online programme
	Citizen Science - Big Seaweed Search
	Crowdsourcing - 'Magnified' transcription projects (complete)
	Citizen Science - Orchid Observers (complete)
	Microverse and Decoding NAture (molecular CitSci)
	Crowdsourcing - Project Plumage (research-based)
	Identification service
	Visiteering
	V-factor volunteering
	Handling programme (including learning volunteers and others - handling stations)
	Investigate centre (handling - targeted at 7-14 year olds)
	Talks / discussions e.g. Nature lives
	Schools programme (shows, workshops)
	Behind the scenes tours

The list of programs shows us variety of audiences, some of the programs targeted at groups from schools, some at families, volunteers, more general group of nature enthusiasts or citizen scientists with specific topic.

With evaluation of educational programs three aspects were followed - use of scientific collections, use of exhibitions, and use of digital collections information in the programs. Also, actual use and potential use was evaluated. The results are presented in table.

Average estimate of collection use in educational programs (scale 0-3).

Institution	The use of scientific collections in program	*The potential for use of scientific collections in program*	The use of exhibitions in program	*The potential for use of exhibitions in program*	The use of digital information of scientific collections in program	*The potential of using digital information of scientific collections in program*
NHM	1,79	*2,00*	0,93	*1,21*	1,50	*2,64*

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MEISE	0,6	*1,4*	0,6	*1,6*	0,4	*1,6*
UTARTU	0,65	*1,17*	2,2	*2,41*	0,94	*2,07*
All programs average	**1,30**	***1,70***	**1,12**	***1,54***	**1,15**	***2,31***

Noteworthy is that there is great variance of estimates between organisations. Collections are most used by the Natural History Museum, London, least used in Meise, the estimate differing almost 3-fold. The exhibitions on the other hand are most used in Tartu compared to other two.

When we look at the relative potential compared to current use of collection content, despite variance elsewhere, all three organisations express a great potential for the growth in the uses of digital content – whether this is for identification; citizen science; or even handling such as 3D prints. Use of exhibitions is almost at its maximum potential in London and Tartu, as for the scientific collection same can be said about London. Although sample size here is small, we believe that variety in fulfilling the potential can be projected to the community of NH collection holders in general. While there is possibly no uniform solution for different stakeholders, the recognition of the opportunity for digital collections in particular is a unifying point.

Relative potential of using collections in educational programs (potential - current use)

	scientific collections	**exhibitions**	**digital information**
NHM	0,21	0,28	**1,14**
MEISE	0,8	1	**1,2**
UTARTU	0,4	0,42	**1,13**
ALL PROGRAMS	0,40	0,42	**1,15**

UTARTU had 53 different school programs separately evaluated; Meise and London grouped them in more general categories. For the comparison of three institutions we aggregated UTARTU school programs and calculated the average score but some details will be shown here:

Use of collections in UTARTU school programs (total 53).

Collection aspect	scientific collections	exhibitions	digital information
Number of programs	9	27	45

Out of nine programs which use scientific collections, two are geology programs about identification of microfossils and microminerals which rely on reference materials. Four programs are about botany and 3 are zoological programs.

2.2.5. Conclusions

While the profiling, survey, and programme evaluation undertaken are qualitative and represent a limited sample of institutions, there are some clear conclusions emerging that we believe hold true more broadly.

First, education (including citizen science activities) is clearly part of the mission of natural history collection holding organisations. While this may often take the form of entertainment and light-touch activities, the intention is to inform, inspire and even to change behaviour and attitudes to the natural world. While size and type of institution makes a difference in emphasis, there is considerable commonality in the provision of education (broadly defined) and the attempt to resource this and develop content and programmes around it.

Second, not surprisingly, our collections are at the heart of this activity, whether directly or as the source of layers of interpretation, and the opportunities cross both physical and digital material and channels. NH collections are objects which readily support a range of educational opportunities, from identification, to data analysis, to the human stories of collection and environmental impact, as well as inspiration for the arts and design.

Third, the scope for use of digital collections and their data is very significant, with greater scope for further development than the use of physical collections for education in general. This includes the use of images or other digital surrogates (even physical objects generated from data such as 3D prints) to enhance learning, allow it to happen remotely, and extend the possible duration of education outside any particular event, programme or visit. Digital techniques offer new insights into collection objects, for instance allowing the structures; interior or composition of an object to be revealed.

2.3 Museum-based citizen science and formal education

Aligned with ICEDIG task 5.1, the Natural History Museum, London reviewed the formal education system in England and how its curriculum interacts with museum-based citizen science. The detailed Review paper is available at appendix 1. This paper identifies current opportunities and challenges relating to engaging school students with museum-led citizen science in the UK, from outdoor fieldwork to the digitisation of natural history museum collections. It also explores the potential development of students' skills in order to support citizen science endeavour. It reviews the education landscape; the types of citizen science; and the mapping to the English curriculum.

This paper concludes that across the primary and secondary curricula, there is a real opportunity to use outdoor fieldwork-based citizen science to teach students about the processes, uses and implications of science, by applying complex subjects from the curriculum to a real world context. While there is already widespread uptake of field-based citizen science within schools, the vast majority of digital collections-based citizen science projects are designed for a general public audience, which tends to result in an adult-centred design and is designed towards individual participation. There is therefore a real opportunity for natural history museums to significantly increase digital access to collections and associated data for students and to develop digital citizen science programmes that are specifically tailored to a schools audience, connecting museums and citizen science with digital elements of the curriculum and exploiting the increasingly sophisticated digital skills such as coding that are becoming mainstreamed within schools. There is also great potential for new kinds of digital citizen science, from digital making to gamified approaches to data modelling.

It is likely that similar opportunities and challeges exist in other countries, and we recommend that similar landscape reviews are carried out if possible.

2.4 Field-based citizen science and natural history collections – overview and case studies

Natural History Museums use a variety of approaches to involve the public in scientific research, including the use of 'Citizen Science'. Citizen science is the practice of involving community volunteers, most of whom are not scientists and will not have had specific scientific training, in the process of scientific research with the intention of broadening public participation in science. This work is often done in collaboration with or under the guidance of expert scientists and scientific institutions. Volunteers usually perform 'large quantities of small, simple and standardized tasks' (Koerten & Besselaar, 2014) such as data collection, categorization, transcription, observation or measurement for projects.

Natural History Museums have a long history of undertaking citizen science activity, and are key actors in the citizen science landscape across Europe and internationally. Whilst some citizen science projects based at NHMs may have strong connections to physical collections, others may have weaker connections and some none at all.

Participation in citizen science projects can be:

- **Online** - People choose a project online and complete a prescribed activity using a PC, laptop or mobile device. Many of these projects focus on data processing or analysis, particularly of images.
  OR
- **Field based** - People go to a specific location/or number of locations to collect data for a project, following a pre-defined protocol (often under the direction of scientists)
  OR
- **A mixture of online & field based** - Many projects involve gathering data in the field as well as online data processing/categorization tasks

The motivations for involvement in projects can vary from participation being a by-product of another interest (eg, gathering ocean temperature data when swimming whilst on holiday), to participation being motivated by a specific interest or passion (eg, gathering information on bird sightings and submitting it to a database) and may be a one off or longer term interaction. Large numbers of volunteers are willing to participate in citizen science projects and this is both inspiring and a fantastic resource. But it is important to acknowledge that the 'motivations of participants differ widely' (Pocock et al 2012). Volunteers may join a project because they are motivated by the subject matter and goals of the project, or they may be interested in gaining specific expertise and skills in order to progress in the world of study or work.

Example field-based projects include:

- **eBird** - A field based project involving birdwatchers making observations of birds and submitting their data to an online database of information that is accessible to scientists, researchers and amateur naturalists.
- **Orchid Observers** - A project where volunteers are asked to photograph wild orchids and upload their images to a website, and also to annotate museum orchid specimens online in order to create a 180 year time-series of flowering data for a range of species to be compared with climate variables.
- **Bioblitzes** - Organisations including museums, universities and research institutions run public events known as bioblitzes. These involve the public in finding and identifying as many species of wildlife in a specific location over a specific period of time, working alongside scientists, naturalists and trained volunteers. Data are most commonly uploaded to a database, helping to create a better picture of biodiversity in a specific location, and specimens may be collected to enhance museum collections.

Physical collections can be both a product of a citizen science project and a resource used in the delivery of that project.

Collections as a resource within a citizen science project

Physical collections can be displayed to engage the public in citizen science events and projects, to demonstrate the target taxa and/or as training aids. For example, specimens can be used when training citizen scientists to accurately carry out identification tasks (see: Supplements, Interviews, NHM London). Physical specimens can also be used as the focus of categorisation, annotation and analysis, as described in the Orchid Observers project where the museum specimens complemented the fieldwork component and helped tell the climate change story and illustrate change over time.

Collections as a product of a citizen science project

A range of citizen science projects have included the development of physical collections at museums and partner institutions. Three case studies are provided below to illustrate different approaches to developing physical collections through citizen science and discuss the opportunities and challenges these approaches present.

2.4.1 Case study 1: The Microverse

Project description: A Natural History Museum, London project looking at the diversity of microscopic life in urban environments. Citizen scientists from 250 schools and colleges across the UK collected samples of microorganisms from the exterior walls of buildings and sent them to the Museum where they were frozen and then DNA sequenced.

Use/development of physical collections: Participants collected biofilms using sterile swabs. DNA was extracted from these samples and samples are stored in the Museum's Molecular Collections Facility and kept for future research.

Opportunities/Challenges:

- DNA sequencing elements of this project took place in the NHM laboratories. Involving participants in more stanges of the process could achieve enhanced outcomes.
- Sequence data were sent back to each school and results will also be published in a peer reviewed journal. However, enhanced technical systems to enable students to manipulate and analyse data themselves would have increased links to curricula and allowed greater learning opportunities.
- Timescales of the project result in long periods with limited contact between research teams and participants. Engagement may drop off at these times.

2.4.2 Case study 2: Lincolnshire Plants

Project description: A project that introduces students to the importance of plants in the modern world, inspires young people to train as botanists and trains volunteers in traditional plant collection, archiving, preparation and mounting of specimens and botanical illustration and photography.

Historical herbarium specimens from Lincolnshire are being digitised and incorporated into the herbarium at the Natural History Museum, with all specimen data and images being publicly accessible online. NHM staff are providing training in identification, specimen preparation and collections care.

Use/development of physical collections:

- The Lincolnshire Naturalists Union historical collections consist of around 9300 specimens which the project is now in the process of re-curating. The recuration involves data transcription and recording in the Museum's CMS, and the mounting and digitisation of historical specimens. Since May 2018 volunteers have been engaged at NHM to work on the project assisting with various curatorial tasks for the historical material.
- New archives of Lincolnshire's plants are also being created by volunteers (under guidance from Lincolnshire Wildlife Trust) as a herbarium for the future.
  c. 4,500 contemporary voucher specimens & 3000 new specimens will be curated, digitised and integrated into the British and Irish herbarium at the NHM and 1500 will be housed within the Joseph Banks Society Centre in Lincolnshire in a new herbarium which will be maintained by volunteers.

Opportunities/Challenges:

- Volunteers are undergoing significant training to develop a present day collection of plants. This investment of time and effort by the managing organisations provides volunteers with valuable skills that may translate across into longer levels of engagement with the project/partner institutions, increased levels of environmental science agency going forward and an ability for trained volunteers to share their skills with others.
- The investment in the development of a new herbarium to reflect the present day diversity of Lincolnshire plants creates a long term legacy, both in terms of the skills and the physical collections.

2.4.3 Case study 3: Decoding Nature

Project description: A project that involved students recording species and habitats, collecting plants to create museum quality specimens and generating DNA sequencing data. This project enabled students to learn a range of skills needed to collaborate with scientists and produce research quality data.

Use/development of physical collections: Voucher specimens were made for molecular collections.

Opportunities/Challenges:

- This project 'used informal and formal science education approaches, so that children are able to understand and connect with the scientific question and become familiar with real data and actual scientific problems' (Tosh et al., 2016). The project also involved working with children over several days so that advanced techniques could be practiced and methods and concepts introduced. The educational elements of this project are particularly inspiring.
- Students were introduced to basic classification, taxonomy and keys and went on to collect 203 specimen accessions, with each student being responsible for 1 data point (or tree). Students then went on to press, dry and mount their specimens. The ownership and responsibility given by this project to citizen scientists again provides an opportunity for other projects.
- The model developed in this project is transferable and applicable elsewhere. However there are costs and other major resource implications. Staff expertise is crucial but not easy to recruit for.

2.4.4 Citizen science, museum collections and learning

Participation in citizen science is known to create learning opportunities for participants. In many of the ways outlined in previous sections, the 'hands on' nature of participating in a field-based citizen science project lends itself to the experiential learning and object-based learning that natural history museums have developed high levels of expertise in. However, citizen science as a practice also brings its own opportunities and affordances for learning. During field based events participants may gain specialist knowledge from scientists and naturalists working alongside them and through the process of following a scientific method or using equipment that they normally wouldn't have access to. Staff involved in field based citizen science may give tutorials to participants before tasks are carried out, either in person or via printed or online resources. Research findings may be shared with participants at the point of participation or data submission, or after a period of time to communicate the results. All of these interactions may develop skills and improve participants' knowledge and understanding - both of the subject matter at hand, broader environmental processes, and of the scientific process in itself.

However aside from this anecdotal evidence, numerous formal studies have identified the skills and learning that have occurred through participation in citizen science projects. A literature review was undertaken and summarised below. Note that this is not comprehensive but aims to capture a range of learning outcomes and research perspectives from across the citizen science practitioner and educational research community.

Table 3: A literature review of learning outcomes from citizen science projects

Learning Outcomes	**Paper**
● Volunteers can reach professional levels of competence, successful collaborative partnerships have been developed between scientists and citizen scientists in fields such as astronomy and ornithology. ● Many citizen scientists collect data using 'standardized and scientifically approved methods'.	(Koerten and Besselaar, 2014), page 6
● Through participation in field based citizen science volunteers 'work in close cooperation with science, thus also learning new scientific insights'	Koerten and Besselaar (2014), page 32
● The scientific literacy of citizen scientists was tested by Cronje et al and it was found that this increased when measured before and after participation. ● Participation in citizen science can also challenge participants attitudes and behaviours towards the environment. Participants also have the opportunity to gain scientific knowledge and explore the physical world and reflect on science.	(Cronje et al., 2011) cited in the above article by Cronje et al (Bonney et al 2009).
● Studies have also shown 'significant increases to social capital' such as political participation, growth of personal networks and community connections	(Crall et al., 2012) page 747
● Participation in this project 'resulted in content learning gains, an increase in process skills, and an increase in self reported intention to engage in pro-environmental activities'. But this report goes on to warn that these are 'tentative conclusions only'.	Crall et al (2012), page 757
● 'Citizen science program participants appear to be more scientifically literate than the general population according to this and other studies'.	Crall et al (2012), page 758

● 'Most citizen science projects also strive to help participants learn about the organisms they are observing and to experience the process by which scientific investigations are conducted (introductory paragraph) ● Evaluations have shown that in addition to learning scientific facts, some participants have used appropriate scientific processes and principles when making decisions about experimental design'.	(Bonney et al., 2009)
● This paper makes reference to scientific literacy outcomes, including: - Improved understanding of science content - enhanced understanding of science process - Better attitudes towards science - Improved skills for conducting science - Increased interest in science as a career The paper suggests projects could measure the above to assess impact, implying that the above are outcomes of projects.	Bonney et al (2009), page 983
● Outcomes described for individual participants include development of new skill sets (Bell et al 2008, Ballard and Belsky 2010), an increased understanding of the process of scientific research (Trumbull et al 2000, Ballard and Belsky 2010), an improved sense of place and/or stewardship (Wilderman et al 2004a, Evans et al Evans et al 2005), and opportunities to deepen relationships with the natural world (Bell et al 2008) as well as other people (Overdevest et al 2004, Bell et al 2008, Kountoupes and Oberhauser 2008).	(Shirk et al., 2012), page 9
● When talking about bioblitz events specifically in the UK this paper mentions - 'adults most frequently cited the opportunity to speak to knowledgeable and enthusiastic people about wildlife as well as finding and learning about particular species' (page 13) - whereas children 'cited practical activities, particularly those that involved direct contact with wildlife'	(Postles and Bartlett, 2018) Bristol Natural History Consortium report
● 'Our findings indicate that youth focused CCS (community & citizen science) can result in ... conservation learning and action. Specifically we found that the connection between youth focussed CCS programs and concrete impacts on conservation... can be...long-term through capacity building for youth in the form of developing their environmental science agency'	(Ballard et al., 2017) Page 73

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• 'Carefully designed citizen-science projects can be successful environments for increasing adult knowledge of factual science'	(Brossard et al., 2005), page 1117
• 'CS programs may have transformative learning potential, but such transformation does not always occur. This type of learning may contribute to the development of individual-level skills, resulting in radical changes in awareness and behaviour related to environmental issues.'	(Bela et al., 2016), page 997
• 'Scientists generally acquire and improve their skills for collaboration and participation and they may over time, change their awareness and expectations with regard to the institutionalised ways of conducting research' • In addition to outcomes for participants, projects also have a scientific contribution and professional scientists can also experience learning outcomes.	Bela et al (2016), page 997 Shirk et al (2012), page 9

In addition to the above learning outcomes, it should be acknowledged that other positive project practices within project delivery may lead to additional learning outcomes for participants. In particular, applying a broader definition of of learning i.e. moving beyond knowledge gain and skills development to include attitudinal, behavioural and affective outcomes is key to gaining a fuller understanding of the benefits and potential outcomes and impacts of Museum-led citizen science. Two such examples of practices that may enhance learning outcomes include:

1. ***Involving participants in decision making***
   - Projects that involve participants in decision making and developing partnerships are 'likely to thrive and increase capacity' (O'Brien et al., 2008)
   - Crall et al 2012 also identifies that outcomes for different types of projects vary eg:
   Contributory - Many citizen science projects fall into this category, members of the public are primarily involved in contributing data and engagement can be limited.
   Collaborative - scientists design the program but the public refines the design, analysing data or disseminating findings and contributing data.
   Co-created - Designed by scientists and the public working together, participants are actively involved in most steps of the scientific process and research questions of common interest are addressed.

   Increased learning outcomes occur for participants involved in the latter category of 'co-created' projects where they are involved with all aspects of the scientific process.

2. ***Developing participants' sense of 'agency' with respect to science***

'Environmental science agency was fostered through participation in three processes at the core of community and citizen science
a) the process of ensuring rigorous data collection and quality
b) the process of disseminating research findings and communicating project work
c) the process of engaging with complex socio-ecological systems as something to act upon

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(Ballard et al, page 73).

Developing skills and knowledge in collection based projects

Analysis of projects and papers in task 5.1 has shown that collections based crowdsourcing projects contribute to the development of a range of digital and natural history skills and knowledge.

Digital skills:

- Data collection, categorisation, transcription and processing
- Digitisation of specimens
- Basic computer skills through use of websites for data entry
- Use of online peer platforms to chat with peers, troubleshoot and learn
- The ability to analyse/interrogate data to draw conclusions
- Involvement in online conversations with experts
- Participation in additional online learning (often to understand language, ideas, concepts that are previously unknown), this could be through keyword searches online, searches for online courses, searches for video tutorials.
- Knowledge of additional computer programmes (eg Excel)
- Technical troubleshooting skills (eg how to upgrade software, use of storage devices for data)
- Pattern recognition skills through repeated exposure to data

Natural history skills and knowledge:

- Identification skills
- Knowledge of archiving (Specimen/voucher specimen preparation, preservation, labelling)
- Creation of new collections
- Collections care
- Usage of specimens for categorization, annotation & analysis
- Detailed knowledge of specific collections/factual knowledge often of specific species
- Specialist knowledge from scientists & naturalists (via tutorials at events, online tutorials or by working alongside them at events)
- Learning to collect data using scientifically approved methods
- Increased scientific literacy in participants
- Experience of the scientific investigation process
- A deeper relationship with the natural world
- Direct contact with wildlife

2.4.5 Conclusions

Although it's understood that participation in citizen science 'can raise people's understanding of science', 'it's potential for driving transformative learning... is underexplored' (Ruiz-Mallén et al., 2016). Bonney et al (Bonney et al., 2016) also states there is 'limited but growing evidence that citizen science projects achieve participant gains...in science knowledge and process, increase public awareness of the diversity of scientific research, and provide deeper meaning to participants' hobbies'. Whilst the above literature review indicates a wide range of potential learning outcomes from citizen science, empirical research to better understand these learning processes is lacking and increased collaboration with educational researchers is required to address this knowledge gap. Current research projects such as LEARN CitSci, the Learning and Environmental Science Agency Research Network for citizen science based at the natural History Museum London and University of California Davis, aim to address such gaps (http://www.nhm.ac.uk/our-science/our-work/science-society-and-skills/learn-citsci-project.html). This research focuses specifically on natural history museum-led citizen science with three NHMs as study sites and practitioner collaborators, and will provide enhanced evidence of the connections between participation in citizen science, the unique roles of collections-holding institutions like natural history museums, and a wide suite of learning outcomes and processes.

3 Business model for engaging the public with collections and collections digitisation

One of the goals of this ICEDIG report is to provide an outline 'business model' or set of principle to help guide future projects that engage citizens with collections, through all forms of education and citizen science. To conclude this report, we present these general principles, and examine public involvement in digitisation / transciption as an example of how each principle could be applied.

When is it worth it?

While the public, or the 'crowd', is sometimes considered to present a free resource to contribute to science, this is not the case. There are always costs in setting up and successfully managing and communicating even light-touch educational or citizen science activities, and a cost-benefit analysis is essential, both beforehand and by periodic reviews to see if projects are achieving their aims.

Before setting up a project or initiative, it is necessary to consider what the aims are, how they will be evaluated, and whether the costs are balanced with these aims. These might include, for example, education, learning or behavioural outcomes; feedback such as surveys that demonstrate positive engagement and responses; or volumes of transcriptions.

Taking digitisation as an example, digitising a multimillion-specimen collection can be a huge task for a museum or other collection holding institution. Automation, digital photography and specialised software will speed up the process but building a digitisation station and training the staff can be expensive or demanding. Commercial outsourcing may be an alternative, however there are only a few digitisation companies in Europe which specialise in natural history collections and are capable of working with larger collections.

Engaging volunteers and citizen scientists in digitisation, for example through crowdsourcing, is one of the methods used by many museums. Usually they step in in the transcription phase when specimens and labels have already been photographed or scanned. It is important to recognise in these cases that the cost-benefit may not be straightforward, and that engaging citizen scientists has a larger impact on the public relations of institutions; an impact on skills, learning and even science policy.

Considerations in deciding on a crowdsourcing approach may therefore include:

- the time and expertise required to choose a platform and set up transcription workflows;
- the compatibility of transcription platforms with your collection management system(s);
- the resources needed to work with volunteers, either in person or providing digital support e.g. via forums, as well as communicating to build an audience for your projects;
- any policy value for engaging citizen scientists;
- any institutional vision for citizen science in general; and
- how you will share the results and what you can offer participants beyond the project.

Define the contributors / audience

As set out in this report, audience segmentation and insight can help your education and citizen science initiatives to be successful. It's useful to consider both your existing audiences, and the requirements of your particular project.

Transcription of collections data, for example, can be very specific work which requires certain skills and sometimes topical interest. Web-based crowdsourcing can be done in anonymous mode and your volunteers can be from all over the world, if you are using international platforms – but you may be looking for particular skills such as language or geographic knowledge; or enthusiasm for a particular group of organisms. It is common for participants in crowdsourcing to include a minority who conduct multiple transcriptions and either are, or become, knowleable in your subject matter; and a larger group who may undertake one or two transcriptions out of general interest. You will need to consider how this will impact your project aims.

Engaging your regular museum visitors in education and citizen science can open up opportunities to deepen their engagement with your collections, and even help to influence their behaviour outside your environment, for instance in how they respond to and look after the natural world.

Engage the contributors

Once the profile of your contributors is planned and monitored, a plan for how to reach them can be developed and set to action.

Setting up your crowdsourcing project, for example, on a relevant platform is not enough to find and attract contributors. Existing platform users have a choice of projects, so you will need to consider what might attract them to yours. New users will need to be made aware that your project exists, and how and why they should contribute. Information can be spread on other channels, for example your institutional website, social media, in person, or via partners such as amateur naturalist groups. You may wish to get help from your institution's communications team or external professionals. Learning the motivations of your audiences is vital for securing their longer-term engagement. There are several research papers on citizen science motivation (Alender, 2016; Jones et al., 2018; Wright et al., 2015) which can be helpful when preparing your communication strategy.

Raise the skill and knowledge level

Once your participants are engaged, you have the opportunity to raise the level of their knowledge, skills and understanding. You will need to consider how to achieve this, and how to measure whether it is successful.

In the case of crowdsourcing transcription, introducing the topic and specifics of the subject can be interesting in itself. Explaining how participants are contributing to research science, and sharing results (such as summaries of research impact), engages participants in the reasons for their activity, increasing their understanding of how collections are used and perhaps raising their general interest in the work of museums and the chance of them interacting with museums in the future, e.g. for volunteering.

There are a range of methods and channels that allow you to provide information such as guides for your participants, and to interact with them e.g. answering questions; thanking them for their work and sharing more general information. If you have engaged physical volunteers, a workshop or museum visit can help them to get more comfortable with the subject. For online volunteers you could prepare tutorials or video coaching, and use forums to discuss the project.

Sustain interest

Tools for increasing skills and knowledge are also relevant to sustaining participation. While the initial contact with the citizen scientist is crucial for establishing your volunteer community, keeping their interest over a longer time is likely to have greater impact both for their skills and knowledge, and for your project goals.

In the Zooniverse portal's (zooniverse.org) participant study, three factors emerged which account for motivation: helping (altruism); social engagement; and interaction (Jones et al., 2018). Similarly the Notes for Nature platform has identified three aspects for user engagement: communication; transcription feedback and narratives; and incentives (Hill et al., 2012).

While direct incentives may not be possible for Museums because of cost, it is worth considering opportunities, for example to offer 'behind the scenes' talks or tours for participants. It is clear, however, that sustained communication is key to project success, including both communication with the institution and with other participants. Engagement and influence on skills and knowledge depend not only on 'broadcasting' information and instructions, but on dialogue.

Appling these five principles or approaches should help maximise the opportunities for collections to be successfully used in citizen science and education to increase the engagement, skills and knowledge of citizens.

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Appendix 1

A review of museum-based citizen science and formal education in England

Shennan, V. and Robinson, L.D. (2019)

Natural History Museum, London

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Contents

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1. Purpose of this document

This document identifies current opportunities and challenges relating to engaging school students with museum-led citizen science, from outdoor fieldwork to the digitisation of natural history museum collections. It also explores the potential development of students' skills in order to support citizen science endeavour.

Countries across the United Kingdom each have different curricula but since the majority of the UK's schools are in England, this document will focus on the English curriculum. Strands of the curriculum that are relevant to museum-led citizen science will be highlighted from Key Stage 1 up to Key Stage 4 (ages 5 – 16 years), including exam criteria up to GCSE level. Beyond GCSE level, subjects are taught by exam board standards and there is little time to expand on the core curricula.

This report focuses on the primary Science curriculum, secondary Biology curriculum, and Geography and Computing curricula across primary and secondary as they are deemed the most relevant to museum-led science research, natural history collections and the digital skills required for the digitisation of these collections.

This report is intended both as an internal resource for Natural History Museum staff, and as guidance for partner museums developing citizen science programming. Furthermore, it feeds into the European Commission-funded ICEDIG programme, task 5.1, exploring the potential of citizen science for digitising museum collections across Europe and beyond.

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2. Introduction

The role of Natural History Museums
Natural History Museums (NHMs) serve a dual purpose of conducting collections-based scientific research and engaging the public with the natural world through these collections. The core remit of these institutions is centred on the acquisition and exchange of knowledge; building new knowledge of the natural world through research programmes and educating visitors though public engagement programmes. Museum-led citizen science feeds into both of these areas, drawing on a combination of collections, scientific research and learning engagement expertise. This mix of expertise means that NHMs are uniquely placed to lead the field in citizen science, innovating new citizen science experiences that can help connect new audiences with the environment and with natural history collections, generate valuable research outcomes, and support the development of vital skills, learning and behavioural outcomes for participants.

Natural history collections hold vast amounts of information that can help to address some of the biggest challenges at this pivotal point in human history, enabling both the academic and policy sectors to better understand critical issues such as the impact of environmental change and biodiversity loss. As society becomes more environmentally aware, socially connected and digitally fluent, there is growing potential to develop citizen science programmes that harness these attitudes and skills, and create platforms for societal engagement with natural world issues.

An audience-centred approach to citizen science
Citizen science creates an opportunity for members of the public to become actively involved in authentic scientific research and explore global issues at a tangible, personal level. Modern digital techniques also provide new opportunities to unlock collections information through crowdsourcing and make it available worldwide. By virtually engaging audiences with this challenge, museums can expand beyond the audiences that can physically visit their sites and accelerate the rate of digitising collections, while extending reach and impact of collections globally.

As biodiversity is decreasing at an alarming rate (WWF, 2018) and urgent action is needed to limit the effects of climate change (IPCC, 2018), never before has it been more pertinent to capture the imagination of young people and engage them with the natural world. Citizen science provides a route for audiences to deepen their engagement with museums and connect with collections and the natural world. It is also a route through which museums can tell the story of their collections and science research, placing the audience in an integral role as part of the process (Robinson et al, 2016). Reflecting audiences and the issues they care about is crucial to attract participants to a project but an audience-focused approach also has to translate into the project design to ensure that it meets participant needs, thus optimising participant retention and data quality (Tweddle et al, 2012). Finding new routes to connect with audiences is critical if we are to make collections more relevant and accessible to a wider range of people and to foster a sense of Environmental Science Agency (Ballard et al, 2017). Through building schools audiences for citizen science using an audience-centred approach, we can help to develop a scientifically literate society that understands and cares about the natural world and feels empowered to take action to protect it for the future.

Citizen science and schools
There are many considerations to take into account when developing a citizen science project, from participant motivations and skillsets, messaging and publicity, to data collection protocols, data analysis and project evaluation. Projects that target a schools audience face additional challenges, as they need to meet curriculum requirements for the target age group, meet the needs of teachers and their class, and be realistic to deliver with a class of 30 children. Participating in a research project with an unknown outcome can be daunting for teachers, so taking part must also add value to a typical lesson. Curricula vary across countries and regions, presenting additional challenges for large-scale or international projects.

Although targeting a schools audience requires extra research and consultation in the planning stages, it also presents a real opportunity to reach a large audience, and develop tailored resources and protocols that are designed for the end-user rather than implementing a one-size-fits-all solution. Well-supported participants will not only produce higher quality data, but will gain more from participation – from increased skills to improved confidence (Tweddle et al, 2012).

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By taking part in museum-led citizen science, students have the opportunity to pursue experiential learning opportunities within a real-world context, while developing their subject knowledge and practical investigation skills. For both teachers and museums, this presents an exciting opportunity to inspire the next generation to engage with nature and take on their role in answering the big science questions of today.

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3. Education landscape in England

Education in England is overseen by the United Kingdom's Department for Education (DfE) which is responsible for children's services and education, including early years, schools, higher and further education policy, apprenticeships and wider skills in England.

The DfE sets the National Curriculum which is a set of subjects and standards used by primary and secondary schools to ensure all children develop the same knowledge as they progress through school. Although most schools including state-funded schools teach the National Curriculum, some types of school including academies and private schools do not have to follow the National Curriculum. This document will focus on connections between the National Curriculum and museum-led citizen science.

All schools are subject to assessment and inspection by the Office for Standards in Education, Children's Services and Skills (Ofsted).

The state-funded education system is divided into Key Stages based upon age. A breakdown of the Key Stages and exam levels can be found in the Appendix.

3.1 STEM skills gap

There is evidence of a growing Science, Technology, Engineering and Math (STEM) skills gap in the UK (STEM Learning, 2018) and a lack of diversity in the STEM sector (CaSE, 2014), impacting pupil attainment in the sciences. Despite this acknowledged skills gap, Maths and English are often prioritised over time spent on science in the primary classroom, as schools in England are under pressure for pupils to excel in Maths and English exams, and this often impacts on the time spent teaching the science curriculum (Wellcome, 2019).

Standard Assessment Test (SATs) papers are taken in English Reading, Maths, and Grammar, Punctuation and Spelling at the end of Key Stage 1 (ages 6-7 years) and Key Stage 2 (ages 10-11 years). Separate SATs papers are also taken in Writing and Science, though these are undertaken as less formal teacher assessments rather than written exams.

Although science is a core subject at primary school, the average curriculum time spent on science in England is 1 hour 24 minutes per week, below the international average of 2 hours. Attainment is low with only 23% of pupils reaching the expected standard at Key Stage 2 in 2016 (Wellcome, 2017).

- In 2016/17 survey on the frequency of science being reported in Ofsted inspections, only 47.8% of reports mentioned science and 15% of reports refer to practical science. This is far behind the 99% of reports that mention mathematics.

- In 2016/17, 81.4% of secondary school Ofsted inspection reports mentioned science, but only 4.5% mentioned practical science.

Assessment is a key driver of teaching and in secondary exams, GCSE and A-level exams, practical experiments no longer contribute to final grades (Wellcome, 2017).

3.2 Student aspirations in science

'Science Capital' is a term used to describe an individual's knowledge, attitudes and experience of science (Archer et al, 2013). The concept of science capital was first developed within the ASPIRES study which tracked the development of young people's science and career aspirations from age 10-14 (from 2009-2013). ASPIRES 2 is continuing to track young people until age 19, to understand the

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changing influences of the family, school, careers education and social identities and inequalities on young people's science and career aspirations (ASPIRES, 2019).

Elements of Science Capital include all the science-related knowledge, attitudes, experiences and resources that you acquire through life, for example knowing someone who works in a scientific discipline, consuming media (TV programmes, magazines etc) with scientific content at home, having a parent with a scientific qualification, talking about science in everyday life, and participating in out-of-school science activities (ASPIRES, 2019).The higher a young person's level of science capital, the more likely they are to consider studying science post-16 and see science as 'for me'.

The ASPIRES research found that, on the whole, most young people aged 10-14 hold relatively high career aspirations but very few young people (approximately 15 percent) aspire to become a scientist. This aspiration remains consistently low across the 10-14 age range and is disproportionately low compared to students' reported interest in science (Archer et al, 2013).

The subsequent Enterprising Science national survey (Science Capital Made Clear, 2016) of 3,658 11-15 year olds in England found that:

- 5% have 'high' science capital – these students more likely to be boys, South Asian and socially advantaged
- 27% have low science capital
- 68% have medium levels of science capital

Participating in citizen science projects may help to build science capital, by providing access to a number of scientific experiences and influences as described above. Many citizen science projects aim to improve scientific literacy and show the relevance of science in everyday life. Projects that give students an opportunity to develop a relationship with a scientist may also demonstrate career pathways and role models in science. Focusing on user-centred design and intentionally building these elements into a citizen science project could lead to greater outcomes for young participants.

3.3 Bridging the gap - Teacher training and confidence in STEM subjects

In the UK, teacher recruitment and retention is an issue, particularly in secondary schools for STEM subjects as subject specialist teachers are important at this level. Currently, only 5% of primary school teachers have a qualification at A level or above in mathematics or science (Morgan et al. 2016).

To help support teachers in these areas, there are a number of organisations providing STEM-specific Continuing Professional Development (CPD) for teachers across the UK (Morgan et al. 2016). Organisations such as the Primary Science Teaching Trust (PSTT), the Association for Science Education (ASE) and STEM Learning, champion science education in the UK and support practitioners through advocacy, networks, CPD, classroom resources, events and conferences. These established organisations evidence that there is demand for practitioner support in STEM education. By developing citizen science projects that are targeted at a schools audience, museums can help support teachers in integrating practical investigations into lessons and support science programming.

Given that there are so many organisations vying for the attention of teachers, it is crucial that any schools initiatives for citizen science work with existing organisations and frameworks, to ensure that they are not in competition with existing resources.

3.4 Tech skills gap - Investment into Computing

In 2014 Computing was introduced to the UK National Curriculum, replacing Information and Communications Technology (ICT), so that children could be introduced to computational thinking from an early age. This radical shift in the curriculum left many schools underprepared, with only 68% of National targets for computing teacher recruitment being met (The Royal Society, 2017). This led to less than half of English schools offering GCSE Computer Science in 2017 (The Royal Society, 2017).

To address this, in 2018 the Government committed £84 million of funding to increase the study of computer science at GCSE, AS and A level and to ensure there is a strong pipeline of digital skills. As part of this programme, a network of Computing Hubs will provide Continuing Professional Development (CPD) and resources for computing teachers in primary and secondary schools and colleges, and facilitate strong links with industry.

The Department for Education confirmed that a consortium of STEM Learning, the Raspberry Pi Foundation and BCS (British Computer Society) - The Chartered Institute for IT, has been chosen to establish the National Centre for Computing Education, to drive excellence in computing education across England.

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4. Types of citizen science

Citizen science is a term used to encompass a very broad range of activities where non-professionals contribute to academic research that generates new knowledge or understanding. Participation can vary in scope and depth, and can take part in a wide variety of settings. We summarise here two key formats of citizen science that are most likely to be undertaken by school groups, and consider the skills development opportunities they afford.

4.1 Outdoor biological recording and environmental monitoring
Biological recording is the scientific study of the presence, abundance, associations and changes, both in time and space, of wildlife. It describes the systematic collection of environmental or species data.

Biological recording can take different forms, from submitting one-off species sightings or environmental observations, to conducting structured wildlife surveys following a set protocol, focused on recording a particular species or habitat or providing a comprehensive species inventory. Biological recording may simply involve visual observations or could involve sampling using a range of survey equipment such as sweep nets, pitfall traps, or malaise traps. BioBlitzes are biological recording events which create a snapshot of the variety of life that can be found within a given area over a set timeframe, usually 24 hours but often shortened to a 'mini-BioBlitz' of e.g. 2 hours. It is an event that brings together professional scientists, species experts, voluntary naturalists and the public to explore outdoors and learn together through biological recording and species identification.

Anyone can make a biological record, from a complete beginner who may submit a single casual observation, to expert amateur naturalists or researchers who may record their observations regularly and have an interest in specific taxonomic groups which may be more difficult to identify. National surveys such as the Big Garden Birdwatch, the Big Butterfly Count, and large number of other citizen science projects and schemes, make it easy for anyone to take part without any expert knowledge or skills.

Mobile applications and websites such as iNaturalist and iRecord allow users to submit observations of any species they come across, which then enter a process of verification and (if of acceptable quality) are shared with local, national and international databases such as the UK National Biodiversity Network Atlas and the Global Biodiversity Information Facility (GBIF).

Opportunities for upskilling students through biological recording
While participants need not have any background knowledge or skills to participate in a citizen science survey or submit an observation, biological recording can help to develop species knowledge and fieldwork skills. Skills that may be enhanced include close observation, description and identification skills, which is a key part of recording species and also physical skills such as using fieldwork tools, following a research protocol and taking accurate measurements.

The Chartered Institute for Ecology and Environmental Management (CIEEM) have highlighted that species identification skills are declining and that this is having an impact on the ecology sector (CIEEM, 2011). In order to address this identification skills gap, it is particularly important that young people are inspired to become naturalists and are supported to develop identification skills. Citizen science can provide an entry point for newcomers to species identification within a structured, supportive framework using simple species keys and supporting resources. For many students, this may be their first experience of taxonomy outside of the classroom. Participation may raise awareness of biodiversity conservation and demonstrate career pathways within the ecology sector, which is important to help inspire the next generation of naturalists (Schuttler et al, 2018) and address the professional skills gaps as identified by CIEEM and others.

4.2 Online or digital citizen science projects
Online citizen science projects often involve analysing and interpreting existing datasets. This kind of project is sometimes called crowdsourcing, as the tasks are often too big for any one person to complete alone. By breaking large datasets into smaller tasks, the power of the crowd can tackle them within a reasonable timeframe. Tasks are often framed as 'challenges' within 'research

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missions', may include 'gamification', league tables or progress bars, and usually have very low barriers to entry.

Projects may take different formats from inviting users to visually categorise or tag images, to transcribing handwritten specimen labels or historic records. There are also more complex projects that encourage user collaboration and may require advanced digital skills including coding. Examples of such projects include Foldit and Eyewire which ask participants to simulate protein folding and model neural pathways respectively.

Opportunities for upskilling students through online citizen science

Most crowdsourcing projects are designed to allow anyone to contribute to real academic research, in their own time, at their own pace. While no prior subject knowledge or specialist skills are usually needed, in order to successfully participate, volunteers may need to follow detailed tutorial instructions, make careful observations and in some instances conduct background research and use problem solving or coding to decipher and classify information that may be difficult to interpret.

By participating in online citizen science, young people may develop their subject knowledge of a field of scientific research, especially if the project theme is relevant to topics covered in their course curricula. The classification process can also build on observation and problem solving skills, while involving young people in the processes of science, such as evaluating project design, data-validation and peer review. Crowdsourcing provides an opportunity for students to use Computing skills in real-world scenarios, use creativity when developing coding that addresses a need and has an unknown outcome, and to work collaboratively with others across the globe. Some crowdsourcing platforms provide forums for discussion, collaboration and/or tools for users to create and manage their own crowdsourcing projects, giving students control and agency over a crowdsourcing activity.

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5. Mapping citizen science to the English curriculum

There are opportunities to incorporate citizen science activity into subjects across the English curriculum but this document will focus on subjects with the greatest relevance to natural history museum collections, both physical and digital, and associated research. This section will explore different ways in which museums might exploit these opportunities and highlight particular challenges museums might face.

The key areas of the curriculum that will be explored are;

- Science: Biology
- Science: Working Scientifically
- Computing
- Geography

5.1 Science: Biology

The Science curriculum consists of various programmes of study which provide the foundations for understanding the world through the disciplines of biology, chemistry and physics. These programmes of study describe a sequence of knowledge and concepts, many of which are built upon and explored in more depth in following years, across the primary curriculum (Key Stage 1 and 2) and lower secondary (Key Stage 3 and 4).

Primary Science is taught for several hours a week in the classroom and is usually delivered by the class teacher, who typically does not have a background in science. The curriculum is divided by topic area rather than split into the science disciplines (Wellcome, 2017).

Secondary Science is taught through the subject disciplines of biology, chemistry and physics and is delivered by a subject specialist teacher.

The national curriculum for science aims to ensure that all pupils:

- develop **scientific knowledge and conceptual understanding** through the specific disciplines of biology, chemistry and physics
- develop understanding of the **nature, processes and methods of science** through different types of science enquiries that help them to answer scientific questions about the world around them
- are equipped with the scientific knowledge required to understand the **uses and implications** of science, today and for the future.

'Working scientifically' specifies the understanding of the nature, processes and methods of science for each year group and it should not be taught as a separate strand. Within this report, it will be explored in the next section.

Opportunities for citizen science: Primary level

The Primary Science curriculum has many biology-based subjects such as Plants, Animals including humans, Seasonal changes, Living things and their habitats and Evolution and inheritance. Within these subjects there are numerous areas that are relevant to outdoor citizen science, from species identification of plants and animals, to observing plant growth, and the changing seasons. There are a number of topics that encourage exploration of your local area such as identifying plants and animals within their habitats or micro-habitats to investigating the human impact on environments. Upper Key Stage 2 focuses on taxonomy though life cycles, classification and reproduction and year 6 covers evolution by exploring how animals have adapted to their environment. Some of these topics can also be enhanced through digital citizen science projects that give these themes a real world context.

Biological recording and environmental monitoring

- There are numerous citizen science projects that involve identifying plants and animals, for example any biological recording activity, from submitting a one off sighting, to taking part in surveys and BioBlitz events.
- Projects such as *Nature's Calendar* involve phenology; observing cyclic and seasonal natural phenomena, in relation to climate and plant and animal life. In the curriculum this relates to observing plant growth, changing seasons, life cycles and reproduction.
- Many biological surveys are trying to understand how environments are changing and how this in turn may have a negative impact on living things (Living things and their habitats, Year 4). For example the *Big Seaweed Search* invites participants to monitor the abundance and distribution of seaweeds around the British Isles. The project mission is to better understand how these coastal habitats are changing by studying the impacts of sea temperature rise, spread on non-native species and ocean acidification.
- Outdoor surveys are a valuable opportunity to show students the nature, processes and methods of science through practical enquiry.

Online or digital projects

- Identification apps such as *iNaturalist* can be used in addition to identification keys to explore the local environment and make recordings with the support of the naturalist community.
- There are numerous digital projects that involve observing animals in different habitats though wildlife capture cameras, which could help put 'Living things and their habitats' into a global context. For example many projects on the *Zooniverse* online platform, such as *Snapshot Serengeti*, involve classifying wildlife images from remote sensor triggered cameras.
- Weather station projects, such as *Raspberry Pi Weather Station for Schools*, allows students to monitor the changing seasons and may be relevant to the human impact on environments (Living things and their habitats, Year 4). This project began in 2016, when the Raspberry Pi Oracle Weather Station programme distributed nearly 1000 weather station kits to schools around the world. This cross-curricular programme included computing and science projects that covered everything digital, from making and networking protocols, to databases and big data.
- Projects that compare historic specimens against living species, such as *Project Plumage*, can be used as a tool to teach Evolution and Inheritance in a practical way.

Opportunities for citizen science: Secondary level

The Key Stage 3 and 4 Biology curriculum has well defined subject areas, which explore topics in depth and may be suitable for citizen science projects that explore complex issues such as interdependencies between organisms and their environment, and genomics.

Biological recording and environmental monitoring

- Relationships in an ecosystem (Key Stage 3), and Ecosystems (Key Stage 4), may have synergies with many biological surveys as these often explore interdependencies between organisms and their environment. This may include projects that investigate the effect of changing environmental factors including plant-pollinator relationships, pollution, changing weather patterns, ocean acidification and the spread and impacts of non-native species.
- Genetics is explored in Key Stage 3. Environmental DNA (eDNA) is genetic material that is found 'free' within the environment i.e. not enclosed within cells, such as within a sample of water from a pond. Environmental samples such as a scoop of soil or sample of pond water can also be sequenced to identify the microscopic organisms present. Citizen science projects focused on gathering and sequencing eDNA are an emerging field of citizen science and these kind of sampling projects may provide a rare chance for students to get involved in genetic sampling and genome sequencing, a type of research that requires expensive equipment and lab processes that may not otherwise be available to schools. *The Microverse* is an example of a project that involved over 120 schools in eDNA sampling for microbial communities on urban buildings. The audience was predominantly older secondary students, (Key Stage 5, 16-18 year olds) outwith the scope of this document, but increasing numbers of similar projects are emerging.

- Ecosystems (Key Stage 4), covers methods of identifying species and measuring distribution, frequency and abundance of species within a habitat. This is an important part of many field surveys.
- Evolution (Key Stage 4), explores developments in biology affecting classification. Museums are constantly exploring new technologies that enhance knowledge of species and may affect taxonomy and classification, so this area may have potential for development of citizen science projects.

Online and digital projects

- Digitising museum collections is a way for students to access a vast number of specimens that otherwise are not on public display, and to gather and process data that can be used to study variation within a species, evolution over time and any number of other factors that require long-term datasets. Many museums are using platforms such as the Zooniverse, Les Herbonautes, Atlas of Living Australia DigiVol and others to digitise collections with the help of the public, for ecological and evolutionary research.
- Natural history museums are repositories of genetic material in the form of specimens and molecular collections. This links with Key Stage 3, Genetics and evolution, which covers importance of maintaining biodiversity and the use of gene banks to preserve hereditary material.

Challenges across primary and secondary curricula

- The Science curriculum across primary and secondary levels is very specific about topics, particularly at Primary level where content is specified by the year rather than just the Key Stage, as in Secondary school. This means that projects would have to be aligned with the curriculum and targeted at a very specific age range, and supporting resources must identify opportunities to scaffold learning across that topic area and key stage.
- We know at Primary level, science is taught for a relatively small proportion of the week, at less than 2 hours on average (Wellcome, 2017). This limits the time available for outdoor, field-based surveys. We recommend that cross-curricular opportunities are identified with the core SATs subjects of maths and English, to enable teachers to incorporate science into other lessons. For example experiment write-ups could be part of English lessons, data analysis could be part of Maths lessons and even field logbooks or specimen sketches could be included in art classes.

5.2 Working Scientifically

'Working Scientifically' specifies the understanding of the nature, processes and methods of science for each year group. It must be embedded in subject content of biology, physics and chemistry rather than taught as a separate strand. The curriculum gives examples of how Working Scientifically might be embedded within topics, so that students learn to use a variety of practical approaches to answer relevant scientific questions. These types of scientific enquiry should include: observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing (controlled investigations); and researching using secondary sources. Pupils should seek answers to questions through collecting, analysing and presenting data (English national curriculum, 2014).

Working Scientifically is a common strand that runs throughout the curriculum topics in both Primary and Secondary science, up to Key Stage 4. Working Scientifically must always be taught through and clearly related to science content in the programme of study. A detailed breakdown of Working Scientifically through the Key Stages can be found in the Appendix of this document.

Opportunities for citizen science

Key stage 1

- observing closely, using simple equipment
- identifying and classifying
- gathering and recording data to help answer questions

Key Stage 2

- making systematic and careful observations, taking accurate measurements using standard units, using a range of equipment
- gathering, recording, classifying and presenting data in a variety of ways to help in answering questions
- recording findings using simple scientific language, drawings, labelled diagrams

Key Stage 3 and 4

Scientific attitudes is brought into the curriculum at Key Stage 3, followed by **The development of scientific thinking** at Key Stage 4. These cover scientific practices including peer review and publishing and communicating results. Working Scientifically also splits into various areas that are relevant to citizen science, including **Experimental skills and investigations** (KS3) **/strategies** (KS4), **Analysis and evaluation**, and **Measurement,** which are broken down into detail in the curriculum.

Biological recording and environmental monitoring

- Experimental Skills and investigations/ strategies (Key Stage 3 and 4) is particularly relevant to field based surveys as these give students an opportunity to follow practical scientific protocols by applying sampling techniques. Observing, identifying and classifying are also key to biological recording.
- Throughout Working Scientifically, there is a focus on getting students to ask relevant questions and use different types of scientific enquiries to answer them (full curriculum in Appendix). An element of student-led, enquiry-based learning could be integrated into project design for example extension activities could be added to projects to enable students to structure their own inquiry around a citizen science survey method. An example of this is the 'Science Experiment' composting activities in the *Earthworm Watch* project which could be tweaked to form the basis of self-led experiments.

Online and digital projects

- Online citizen science projects could make their data freely available, easy to access and formatted in such a way that it is easy to use, to allow students to conduct their own independent data analysis and communicate their results. Data analysis using statistical techniques is introduced in Key Stage 3, and expanded upon in Key Stage 4.
- Analysis and evaluation runs through Key Stage 3 and 4 with many areas that could be explored with citizen science datasets, including but not limited to:
    - interpreting observations and other data, including identifying patterns and trends, making inferences and drawing conclusions
    - evaluate data, showing awareness of potential sources of random and systematic error (Key Stage 3)
    - identify further questions arising from their results (Key Stage 3)
    - representing distributions of results and making estimations of uncertainty (Key Stage 4)
    - presenting reasoned explanations, including relating data to hypotheses (Key Stage 4)

- being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error (Key Stage 4)

Challenges across primary and secondary

- One of the main challenges when covering the Working Scientifically curriculum at Primary level is the time available to dedicate to science, after literacy and numeracy. One way to address this in citizen science projects could be highlighting cross-curricular opportunities and embedding this approach into projects.
- At Primary level, many teachers lack a science background and may not have specialist equipment or knowledge of how to do practical science, resulting in a lack of confidence in taking up citizen science opportunities. To address this, citizen science projects could support teachers through CPD, providing tailored supporting materials such as online tutorials or guides which give practical advice about how to conduct practical citizen science surveys with a class, ideally developed in consultation or collaboration with Primary teachers. Projects may also need to provide the necessary equipment, or guidance on how to source it, to ensure the project is accessible to schools that may not have the supplies needed.
- At Secondary level there is less time spent on practical science, with only 4.5% of Ofsted inspection reports mentioning practical science as a strength in 2016/17 (Wellcome, 2017). Teachers are under increasing pressure to cover exam material and practical science is no longer examined. Demonstrating the value of practical citizen science for learning specific concepts and the practical knowledge needed in written exams may help to justify spending time on citizen science projects. Projects targeting older students, from Key Stage 4 and up, should specify links with particular exam board standards which are more specific than the National Curriculum.

5.3. Computing

The Computing curriculum equips students to use computational thinking and creativity to understand and change the world. Computing has deep links with mathematics, science, and design and technology, and provides insights into both natural and artificial systems. The core of Computing is computer science, in which pupils are taught the principles of information and computation, how digital systems work, and how to put this knowledge to use through programming. Building on this knowledge and understanding, pupils are equipped to use information technology to create programs, systems and a range of content. Computing also ensures that pupils become digitally literate – able to use, express themselves and develop their ideas through information and communication technology – at a level suitable for the future workplace and as active participants in a digital world.

The national curriculum for Computing aims to ensure that all pupils:

- can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation
- can analyse problems in computational terms, and have repeated practical experience of writing computer programs in order to solve such problems
- can evaluate and apply information technology, including new or unfamiliar technologies, analytically to solve problems
- are responsible, competent, confident and creative users of information and communication technology.

ICT used to focus purely on computer literacy – teaching pupils how to use existing computer software programmes for tasks such as word-processing or creating spreadsheets. This has been replaced by the new Computing curriculum which teaches children programming skills as a long-term solution to address the skills gap between technology sector jobs and the people qualified to work in the technology industry.

- At Key Stage 1 (5-6 year olds): pupils will learn what algorithms are and begin to use logical reasoning skills and begin to create simple programmes and de-bug these using visual coding platforms, such as Scratch.

- By Key Stage 2 (7-11 year olds) students get more practice using software on a range of digital devices to design and create a range of programs, systems and content that accomplish given goals, including using devices for collecting, analysing and presenting back data and information.
- In Secondary school, Key Stage 3 (11-13 year olds) children will begin to expand their programming languages and use these to create their own programmes. At this stage, schools are free to choose the specific coding languages and tools. Boolean logic, binary numbers, and studying how hardware and software work together are part of the curriculum.
- By Key Stage 4 the curriculum is less prescriptive. Students have opportunities to develop and apply their analytic, problem-solving, design, and computational thinking skills and undertake creative projects.

Opportunities for citizen science

The focus of the Computing curriculum is on computational thinking and building programming skills; this covers computer science, information technology and digital literacy.

'Digital making' describes learning about technology through making with it (Quinlan, 2015). Digital making fits well within this curriculum and is an approach that is advocated by the National Centre for Computing Education through their partnership with the Raspberry Pi Foundation, who provide CPD to teachers via the FutureLearn online platform. These courses are free for anyone to sign up to but they also contribute to computing accreditation for teachers. Citizen science projects involving digital making would give students a real world context to apply their coding skills.

Biological recording and environmental monitoring

- At Primary level (Key Stage 1and 2) digital making for citizen science can illustrate uses of technology beyond school. This could be as simple as building a wildlife capture camera as a class. An example of this is the NatureBytes NestBoxes project which was set up in schools across Belgium (NatureBytes, 2019).
- By Secondary level (Key Stage 3), digital making would meet key criteria around creating complex projects that can be used to collect and analyse data, meeting the needs of a target audience:
    - undertake creative projects that involve selecting, using, and combining multiple applications, preferably across a range of devices, to achieve challenging goals, including collecting and analysing data and meeting the needs of known users
    - create, re-use, revise and re-purpose digital artefacts for a given audience, with attention to trustworthiness, design and usability

Online or digital projects

- At Key Stage 2 there may opportunities for digitally connected projects such as global weather stations as in the UK School Seismology Project (British Geological Survey 2019) or crowdsourced projects where the users are involved in discussion forums and validating or ranking results. [Students will]:
    - understand computer networks including the internet; how they can provide multiple services, such as the world wide web; and the opportunities they offer for communication and collaboration
    - use search technologies effectively, appreciate how results are selected and ranked, and be discerning in evaluating digital content
- By Key Stage 3, students learn about data modelling and there may be an opportunity for crowdsourced citizen science projects that involve gamified modelling that mimics or explores real world data, such as Foldit (protein folding puzzle) or EyeWire (mapping 3D neurons). [Students will]:
    - design, use and evaluate computational abstractions that model the state and behaviour of real-world problems and physical systems
- Sharing datasets from online citizen science projects could provide students with an opportunity to mine the data for meaningful conclusions. The Institute for Research in Schools (IRIS) make

data accessible to schools, provide teacher training and resources, and lend out scientific research equipment. [Students will]:

- understand how instructions are stored and executed within a computer system; understand how data of various types (including text, sounds and pictures) can be represented and manipulated digitally, in the form of binary digits

Challenges across primary and secondary curricula

- Since the Computing curriculum is relatively new and the Government has invested heavily in teacher CPD in this area with the Raspberry Pi Foundation, there will be a bias for schools to work with the devices that teachers trained with. While other mini-computers and digital making devices are available, it may be easiest to align any digital making projects with the CPD available.
- Shaping data into a form that is accessible, usable and has appropriate data sharing licensing may be a challenge when making datasets available to schools. In order for students to come up with meaningful results, there may be a need for teacher training and the creation of class resources to support students.
- Interactive digital modelling projects may be engaging and relevant to students but these types of projects may only be suitable for very specific research questions, and may require significant time and money to develop which is often beyond the scope of most citizen science initiatives.
- We recommend that citizen science projects that wish to have a strong digital element and tap into the Computing curriculum allocate appropriate budget at the outset to facilitate this and increase chances of successful learning and engagament.

5.4 Geography

The Geography curriculum should inspire in students a curiosity about the natural word. The programmes of study should build knowledge about diverse places, people, resources and natural and human environments, together with a deep understanding of the Earth's key physical and human processes.

The national curriculum for geography aims to ensure that all pupils:

- develop contextual knowledge of the location of globally significant places – both terrestrial and marine – including their defining physical and human characteristics and how these provide a geographical context for understanding the actions of processes
- understand the processes that give rise to key physical and human geographical features of the world, how these are interdependent and how they bring about spatial variation and change over time
- are competent in the geographical skills needed to:
    - collect, analyse and communicate with a range of data gathered through experiences of fieldwork that deepen their understanding of geographical processes
    - interpret a range of sources of geographical information, including maps, diagrams, globes, aerial photographs and Geographical Information Systems (GIS)
    - communicate geographical information in a variety of ways, including through maps, numerical and quantitative skills and writing at length.

The National curriculum covers Key Stage 1 – 3, as Key Stage 4 and beyond is covered in the exam board standards.

Opportunities for citizen science

The Geography curriculum has a focus on practical skills used in fieldwork such as map reading and observational skills which are highly relevant to outdoor citizen science. There is also an emphasis on the human relationship and impact on the environment, which is relevant to the core messages and mission of many citizen science projects.

Outdoor field work and environmental monitoring

- Geographical skills and fieldwork are taught from Key Stage 1-3.
    - At Key Stage 1 this covers using simple fieldwork skills to observe key human and physical features of the school grounds and surrounding environment.
    - At Key Stage 2 there is more focus on learning methods:
      "use fieldwork to observe, measure, record and present the human and physical features in the local area using a range of methods, including sketch maps, plans and graphs, and digital technologies."

- Human and physical geography is also taught from Key Stage 1-3.
    - At Key Stage 1 this is simply identifying seasonal and daily weather patterns and using geographic vocabulary.
    - At Key Stage 2 students must describe key concepts of human and physical geography. Physical geography is most relevant to citizen science and this includes: climate zones, biomes and vegetation belts, rivers, mountains, volcanoes and earthquakes, and the water cycle
    - At Key Stage 3 the natural systems topic may have relevance for citizen science projects: "understand how human and physical processes interact to influence and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems"

- Human geography may have potential to link with lessons in citizenship. The most recent Ofsted report on Geography highlighted that "By paying greater attention to literacy, the global dimension of geography and the use of topical exemplars, teachers enhanced pupils' learning, engaged them and made lessons more interesting and enjoyable." (Ofsted, 2011)

Online or digital projects

- Geographical skills and fieldwork
    - There may be opportunity to integrate digital making into outdoor fieldwork.
      At Key Stage 3 there is a focus on data processing:
      "use fieldwork in contrasting locations to collect, analyse and draw conclusions from geographical data, using multiple sources of increasingly complex information."

Challenges across primary and secondary curricula

- The Geography curriculum is less detailed than the Science curriculum, and doesn't cover Key Stage 4. If targeting GCSE level (Key Stage 3 and 4) then exam board standards break down these topics into more detail. If exam board criteria aren't taken into account then there is the possibility that curriculum links may not be specific enough to appeal to teachers or and resources may not provide them with enough support.
- Similarly to Science, Geography can be a neglected part of the curriculum in Primary schools as teachers may lack the practical skills and confidence or time available after Maths and English have been prioritised.
- Outdoor learning can be a challenge for teachers due to lack of confidence teaching outside the classroom and concerns about health and safety risk along with curriculum pressures (Waite et al., 2016).
- The 2011 Ofsted report found that at approximately one in 10 of the 91 primary schools visited, geography was more or less disappearing. This illustrates the importance of demonstrating the cross-curricular connections for citizen science projects targeting Primary schools (Ofsted, 2011).

6. Conclusions and recommendations

Across the primary and secondary curricula there is a real opportunity to use outdoor fieldwork-based citizen science to teach students about the processes, uses and implications of science, by applying complex subjects from the curriculum to a real world context. There is already widespread uptake of field-based citizen science within schools, so increasing the quality of student experience and maximising outcomes for students by applying user-centred design is a relatively easy 'win' for museums and other citizen science practitioners.

The vast majority of digital collections-based citizen science projects are designed for a general public audience, which tends to result in an adult-centred design and is designed towards individual participation. There remains a real opportunity for natural history museums to significantly increase digital access to collections and associated data for students and to develop digital citizen science programmes that are specifically tailored to a schools audience. Whilst some projects currently exist in this area, there is a significant missed opportunity to connect museums and citizen science with digital elements of the curriculum and to exploit the increasingly sophisticated digital skills such as coding that are becoming mainstreamed within schools. There is also great potential for new kinds of digital citizen science, from digital making to gamified approaches to data modelling. Such innovations will be welcomed, but must be appropriately resourced and delivered to ensure success, and it is acknowledged that many citizen science projects run on limited budgets and may not have the resources to exploit these opportunities fully.

Mapping activities to the curriculum

Teachers are under considerable time pressure to deliver on the curriculum. This means that projects targeting a schools audience must align with the curriculum and add value to a typical lesson in order to appeal to teachers. Providing resources that are quick and easy to use that increase teachers' confidence in delivering the activity are key.

At Primary level, there is greater emphasis on developing literacy and numeracy, leaving little time for delivering the science curriculum. To address this, citizen science projects should highlight cross-curricular opportunities for Maths, English, Geography and/or Computing to justify time spent on projects. This multi-disciplinary approach would give students the opportunity to develop and apply a range of skills in a real world context, and enable teachers to dedicate more significant chunks of teaching time to any given citizen science project.

In Secondary school, whilst Science gets more time allocation than previously, there is still little time available for practical science. Focusing on the investigation of difficult concepts in the curriculum and real world application of science topics may give a museum-led citizen science project an edge over a typical classroom lesson. Digital collections may be a valuable source of data on variation within species and adaptation over time. Sharing datasets from online citizen science projects could provide students with an opportunity to conduct data analysis and mine the data for meaningful results. However to enable students to effectively conduct data analysis, data must be easy to access and formatted in such a way that they are easy to use and with appropriate licensing for their use in this context. Projects that showcase the myriad uses of museum specimens and molecular collections can demonstrate the importance of maintaining biodiversity and preserving genetic material, connecting schools with museum-based contemporary biodiversity research.

Working closely with teachers during the research and development of citizen science projects will ensure projects meet the curriculum specifications, deliver on learning outcomes, and fit with the timeframe and structure of the school year.

Collaborating with teachers: Working within existing frameworks

It is crucial that any schools initiatives for citizen science work with existing education organisations and frameworks, to ensure that they reach target audiences and are not in competition with existing resources. The STEM education sector has a variety of advocacy networks that provide STEM-specific teacher continuing professional development, networking opportunities to connect teachers and access to online resources, at both national and regional level.

The newly established National Centre for Computing Education has been set up to support teacher training for the Computing curriculum. Aligning any digital making citizen science projects with their training courses would ensure that projects are pitched at the right level for teachers. This approach may make it easier to market projects to digitally engaged teachers, who are interested in practical projects to apply their newly acquired skills in the classroom.

Teacher consultation and piloting projects in the classroom are essential steps in successfully developing citizen science projects for schools audiences. This takes time and resource, and participating schools and teachers should be adequately recognised for their input to this stage of project development. It is vital that citizen science project developers take these factors into account when planning the development phases of a new citizen science initiative. Investing at this stage will pay off in the long run as participation and retention rates and data quality are likely to be higher as a consequence.

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8.Appendix

Breakdown of school years

Key Stage	Primary/ secondary	Year	Final exam	Age
Early Years	**Primary**	Nursery (or Pre-School)		3-4
		Reception (or Foundation)		4-5
Key Stage 1		Year 1		5-6
		Year 2	Some schools sit SATs at the end of Key Stage 1	6-7
Key Stage 2		Year 3		7-8
		Year 4		8-9
		Year 5		9-10
		Year 6	SATs. Optional grammar school exam, often the 11-plus	10-11
Key Stage 3	**Secondary**	Year 7		11-12
		Year 8		12-13
		Year 9		13-14
Key Stage 4		Year 10		14-15
		Year 11	GCSE	15-16
Key Stage 5	**Sixth form college**	Year 12	Advanced subsidiary level	16-17
		Year 13	A level	17-18

Curriculum Extracts: Primary Science

Primary Science Curriculum			
Key Stage	Year	Subject	Content
1	1	Plants	• identify and name a variety of common wild and garden plants, including deciduous and evergreen trees Non-statutory guidance • Pupils might keep records of how plants have changed over time, • observing growth of flowers and vegetables
		Animals, including humans	• identify and name a variety of common animals including fish, amphibians, reptiles, birds and mammals • identify and name a variety of common animals that are carnivores, herbivores and omnivores
		Seasonal changes	• observe changes across the four seasons • observe and describe weather associated with the seasons and how day length varies Non-statutory guidance • Pupils might work scientifically by: making tables and charts about the weather; and making displays of what happens in the world around them, including day length, as the seasons change.
	2	Living things and their habitats	• identify that most living things live in habitats to which they are suited and describe how different habitats provide for the basic needs of different kinds of animals and plants, and how they depend on each other • identify and name a variety of plants and animals in their habitats, including micro-habitats
		Plants	Non-statutory guidance • Pupils should use the local environment throughout the year to observe how different plants grow.
		Animals, including humans	• notice that animals, including humans, have offspring which grow into adults
2	3	Plants	• identify and describe the functions of different parts of flowering plants: roots, stem/trunk, leaves and flowers • explore the requirements of plants for life and growth (air, light, water, nutrients from soil, and room to grow) and how they vary from plant to plant • explore the part that flowers play in the life cycle of flowering plants, including pollination, seed formation and seed dispersal.
	4	Living things and their habitats	• recognise that living things can be grouped in a variety of ways • explore and use classification keys to help group, identify and name a variety of living things in their local and wider environment

			• recognise that environments can change and that this can sometimes pose dangers to living things. Non-statutory guidance • Pupils should explore examples of human impact (both positive and negative) on environments, for example, the positive effects of nature reserves, ecologically planned parks, or garden ponds, and the negative effects of population and development, litter or deforestation. • Pupils might work scientifically by: using and making simple guides or keys to explore and identify local plants and animals; making a guide to local living things; raising and answering questions based on their observations of animals and what they have found out about other animals that they have researched.
		Animals, including humans	• construct and interpret a variety of food chains, identifying producers, predators and prey.
	5	Living things and their habitats	• describe the differences in the life cycles of a mammal, an amphibian, an insect and a bird • describe the life process of reproduction in some plants and animals.
	6	Living things and their habitats	• describe how living things are classified into broad groups according to common observable characteristics and based on similarities and differences, including micro-organisms, plants and animals • give reasons for classifying plants and animals based on specific characteristics. Non-statutory guidance • Pupils might work scientifically by: using classification systems and keys to identify some animals and plants in the immediate environment. They could research unfamiliar animals and plants from a broad range of other habitats and decide where they belong in the classification system.
		Evolution and inheritance	• identify how animals and plants are adapted to suit their environment in different ways and that adaptation may lead to evolution.

Curriculum Extracts: Secondary Science

Secondary Science Curriculum: Biology		
Key Stage	Subject	Content
3	Interactions and interdependencies	Relationships in an ecosystem • the interdependence of organisms in an ecosystem, including food webs and insect pollinated crops • the importance of plant reproduction through insect pollination in human food security • how organisms affect, and are affected by, their environment, including the accumulation of toxic materials.
	Genetics and evolution	Inheritance, chromosomes, DNA and genes • heredity as the process by which genetic information is transmitted from one generation to the next • differences between species • the variation between individuals within a species being continuous or discontinuous, to include measurement and graphical representation of variation • the variation between species and between individuals of the same species means some organisms compete more successfully, which can drive natural selection • changes in the environment may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction • the importance of maintaining biodiversity and the use of gene banks to preserve hereditary material.
4	Ecosystems	• levels of organisation within an ecosystem • some abiotic and biotic factors which affect communities; the importance of interactions between organisms in a community • how materials cycle through abiotic and biotic components of ecosystems • the role of microorganisms (decomposers) in the cycling of materials through an ecosystem • organisms are interdependent and are adapted to their environment • the importance of biodiversity • methods of identifying species and measuring distribution, frequency and abundance of species within a habitat • positive and negative human interactions with ecosystems.

	Evolution, inheritance and variation	• the genome as the entire genetic material of an organism • how the genome, and its interaction with the environment, influence the development of the phenotype of an organism • the potential impact of genomics on medicine • most phenotypic features being the result of multiple, rather than single, genes • single gene inheritance and single gene crosses with dominant and recessive phenotypes • sex determination in humans • genetic variation in populations of a species • the process of natural selection leading to evolution • the evidence for evolution • developments in biology affecting classification • the importance of selective breeding of plants and animals in agriculture • the uses of modern biotechnology including gene technology; some of the practical and ethical considerations of modern biotechnology.

Curriculum extracts: Working Scientifically

Key Stage 1 & 2
During years 1 and 2, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content:

- asking simple questions and recognising that they can be answered in different ways
- observing closely, using simple equipment
- performing simple tests
- identifying and classifying
- using their observations and ideas to suggest answers to questions
- gathering and recording data to help in answering questions.

During years 3 and 4, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content:

- asking relevant questions and using different types of scientific enquiries to answer them
- setting up simple practical enquiries, comparative and fair tests
- making systematic and careful observations and, where appropriate, taking accurate measurements using standard units, using a range of equipment, including thermometers and data loggers
- gathering, recording, classifying and presenting data in a variety of ways to help in answering questions
- recording findings using simple scientific language, drawings, labelled diagrams, keys, bar charts, and tables
- reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions
- using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions
- identifying differences, similarities or changes related to simple scientific ideas and processes
- using straightforward scientific evidence to answer questions or to support their findings.

During years 5 and 6, pupils should be taught to use the following practical scientific methods, processes and skills through the teaching of the programme of study content:

- planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary
- taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate
- recording data and results of increasing complexity using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs
- using test results to make predictions to set up further comparative and fair tests
- reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations
- identifying scientific evidence that has been used to support or refute ideas or arguments.

Key Stage 3
Scientific attitudes

- pay attention to objectivity and concern for accuracy, precision, repeatability and reproducibility

- understand that scientific methods and theories develop as earlier explanations are modified to take account of new evidence and ideas, together with the importance of publishing results and peer review
- evaluate risks.

Experimental skills and investigations

- ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience
- make predictions using scientific knowledge and understanding
- select, plan and carry out the most appropriate types of scientific enquiries to test predictions, including identifying independent, dependent and control variables, where appropriate
- use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, paying attention to health and safety
- make and record observations and measurements using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements
- apply sampling techniques.

Analysis and evaluation

- apply mathematical concepts and calculate results
- present observations and data using appropriate methods, including tables and graphs
- interpret observations and data, including identifying patterns and using observations, measurements and data to draw conclusions
- present reasoned explanations, including explaining data in relation to predictions and hypotheses
- evaluate data, showing awareness of potential sources of random and systematic error
- identify further questions arising from their results.

Measurement

- understand and use SI units and IUPAC (International Union of Pure and Applied Chemistry) chemical nomenclature
- use and derive simple equations and carry out appropriate calculations
- undertake basic data analysis including simple statistical techniques.

Key Stage 4
The development of scientific thinking

- the ways in which scientific methods and theories develop over time

- using a variety of concepts and models to develop scientific explanations and understanding
- appreciating the power and limitations of science and considering ethical issues which may arise
- explaining everyday and technological applications of science; evaluating associated personal, social, economic and environmental implications; and making decisions based on the evaluation of evidence and arguments
- evaluating risks both in practical science and the wider societal context, including perception of risk
- recognising the importance of peer review of results and of communication of results to a range of audiences.

Experimental skills and strategies

- using scientific theories and explanations to develop hypotheses
- planning experiments to make observations, test hypotheses or explore phenomena
- applying a knowledge of a range of techniques, apparatus, and materials to select those appropriate both for fieldwork and for experiments
- carrying out experiments appropriately, having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations

- recognising when to apply a knowledge of sampling techniques to ensure any samples collected are representative
- making and recording observations and measurements using a range of apparatus and methods
- evaluating methods and suggesting possible improvements and further investigations.

Analysis and evaluation

- applying the cycle of collecting, presenting and analysing data, including:
- presenting observations and other data using appropriate methods
- translating data from one form to another
- carrying out and representing mathematical and statistical analysis
- representing distributions of results and making estimations of uncertainty
- interpreting observations and other data, including identifying patterns and trends, making inferences and drawing conclusions
- presenting reasoned explanations, including relating data to hypotheses
- being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error
- communicating the scientific rationale for investigations, including the methods used, the findings and reasoned conclusions, using paper-based and electronic reports and presentations.

Vocabulary, units, symbols and nomenclature

- developing their use of scientific vocabulary and nomenclature
- recognising the importance of scientific quantities and understanding how they are determined
- using SI units and IUPAC chemical nomenclature unless inappropriate
- using prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano)
- interconverting units
- using an appropriate number of significant figures in calculations.

Curriculum extracts: Computing

Computing curriculum	
Key Stage	Content
1	• understand what algorithms are; how they are implemented as programs on digital devices; and that programs execute by following precise and unambiguous instructions • create and debug simple programs • use logical reasoning to predict the behaviour of simple programs • use technology purposefully to create, organise, store, manipulate and retrieve digital content • recognise common uses of information technology beyond school • use technology safely and respectfully, keeping personal information private; identify where to go for help and support when they have concerns about content or contact on the internet or other online technologies.
2	• design, write and debug programs that accomplish specific goals, including controlling or simulating physical systems; solve problems by decomposing them into smaller parts • use sequence, selection, and repetition in programs; work with variables and various forms of input and output • use logical reasoning to explain how some simple algorithms work and to detect and correct errors in algorithms and programs • understand computer networks including the internet; how they can provide multiple services, such as the world wide web; and the opportunities they offer for communication and collaboration • use search technologies effectively, appreciate how results are selected and ranked, and be discerning in evaluating digital content • select, use and combine a variety of software (including internet services) on a range of digital devices to design and create a range of programs, systems and content that accomplish given goals, including collecting, analysing, evaluating and presenting data and information • use technology safely, respectfully and responsibly; recognise acceptable/unacceptable behaviour; identify a range of ways to report concerns about content and contact.
3	• design, use and evaluate computational abstractions that model the state and behaviour of real-world problems and physical systems • understand several key algorithms that reflect computational thinking [for example, ones for sorting and searching]; use logical reasoning to compare the utility of alternative algorithms for the same problem • use two or more programming languages, at least one of which is textual, to solve a variety of computational problems; make appropriate use of data structures [for example, lists, tables or arrays]; design and develop modular programs that use procedures or functions • understand simple Boolean logic [for example, AND, OR and NOT] and some of its uses in circuits and programming; understand how numbers can be represented in binary, and be able to carry out simple operations on binary numbers [for example, binary addition, and conversion between binary and decimal] • understand the hardware and software components that make up computer systems, and how they communicate with one another and with other systems • understand how instructions are stored and executed within a computer system; understand how data of various types (including text, sounds and pictures) can be represented and manipulated digitally, in the form of binary digits

	• undertake creative projects that involve selecting, using, and combining multiple applications, preferably across a range of devices, to achieve challenging goals, including collecting and analysing data and meeting the needs of known users • create, re-use, revise and re-purpose digital artefacts for a given audience, with attention to trustworthiness, design and usability • understand a range of ways to use technology safely, respectfully, responsibly and securely, including protecting their online identity and privacy; recognise inappropriate content, contact and conduct and know how to report concerns.
4	• develop their capability, creativity and knowledge in computer science, digital media and information technology • develop and apply their analytic, problem-solving, design, and computational thinking skills • understand how changes in technology affect safety, including new ways to protect their online privacy and identity, and how to identify and report a range of concerns.

Curriculum extracts: Geography

Geography Curriculum		
Key Stage	Subject	Content
1	Place knowledge	• understand geographical similarities and differences through studying the human and physical geography of a small area of the United Kingdom, and of a small area in a contrasting non-European country
	Human and physical geography	• identify seasonal and daily weather patterns in the United Kingdom and the location of hot and cold areas of the world in relation to the Equator and the North and South Poles • use basic geographical vocabulary to refer to: ○ key physical features, including: beach, cliff, coast, forest, hill, mountain, sea, ocean, river, soil, valley, vegetation, season and weather ○ key human features, including: city, town, village, factory, farm, house, office, port, harbour and shop
	Geographical skills and fieldwork	• use world maps, atlases and globes to identify the United Kingdom and its countries, as well as the countries, continents and oceans studied at this key stage • use simple compass directions (North, South, East and West) and locational and directional language [for example, near and far; left and right], to describe the location of features and routes on a map • use aerial photographs and plan perspectives to recognise landmarks and basic human and physical features; devise a simple map; and use and construct basic symbols in a key • use simple fieldwork and observational skills to study the geography of their school and its grounds and the key human and physical features of its surrounding environment.

2	Place knowledge	• understand geographical similarities and differences through the study of human and physical geography of a region of the United Kingdom, a region in a European country, and a region within North or South America
	Human and physical geography	• describe and understand key aspects of: o physical geography, including: climate zones, biomes and vegetation belts, rivers, mountains, volcanoes and earthquakes, and the water cycle o human geography, including: types of settlement and land use, economic activity including trade links, and the distribution of natural resources including energy, food, minerals and water
	Geographical skills and fieldwork	• use maps, atlases, globes and digital/computer mapping to locate countries and describe features studied • use the eight points of a compass, four and six-figure grid references, symbols and key (including the use of Ordnance Survey maps) to build their knowledge of the United Kingdom and the wider world • use fieldwork to observe, measure, record and present the human and physical features in the local area using a range of methods, including sketch maps, plans and graphs, and digital technologies.
3	Human and physical geography	• understand, through the use of detailed place-based exemplars at a variety of scales, the key processes in: o physical geography relating to: geological timescales and plate tectonics; rocks, weathering and soils; weather and climate, including the change in climate from the Ice Age to the present; and glaciation, hydrology and coasts o human geography relating to: population and urbanisation; international development; economic activity in the primary, secondary, tertiary and quaternary sectors; and the use of natural resources • understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems
	Geographical skills and fieldwork	• build on their knowledge of globes, maps and atlases and apply and develop this knowledge routinely in the classroom and in the field • interpret Ordnance Survey maps in the classroom and the field, including using grid references and scale, topographical and other thematic mapping, and aerial and satellite photographs • use Geographical Information Systems (GIS) to view, analyse and interpret places and data • use fieldwork in contrasting locations to collect, analyse and draw conclusions from geographical data, using multiple sources of increasingly complex information.